Naval Surface Warfare Center
Carderock Division
West Bethesda, Maryland 20817-5700

NSWCCD-50-TR-2007/052 October 2007

Hydromechanics Department Report

MASK WAVES BENCHMARK

by
Timothy C. Smith
Lauren K. Hanyok
Michael J. Hughes

Naval Surface Warfare Center
Carderock Division
West Bethesda, Maryland 20817-5700

NSWCCD-50-TR-2007/052 October 2007

Hydromechanics Department Report

MASK WAVES BENCHMARK

by
Timothy C. Smith
Lauren K. Hanyok
Michael J. Hughes

Approved for public release: Distribution Unlimited.

NSWCCD-50-TR-2007/052 MASK Waves Benchmark

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From-To)*
30-10-2007	Final	Feb 2007-Jul 2007

4. TITLE AND SUBTITLE
MASK WAVES BENCHMARK

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
TIMOTHY C. SMITH, LAUREN K. HANYOK, MICHAEL J. HUGHES

5d. PROJECT NUMBER

5e. TAKS NUMBER

5f. WORK UNIT NUMBER
99-1-5013-024-14

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NAVAL SURFACE WARFARE CENTER CARDEROCK DIVISION
9500 MACARTHUR BLVD
WEST BETHESDA, MD 20817-5700

8. PREFORMING ORGANIZATION REPORT NUMBER
NSWCCD-50-TR-2007/052

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
NAVAL SURFACE WARFARE CENTER CARDEROCK DIVISION
9500 MACARTHUR BLVD
WEST BETHESDA, MD 20817-5700

10. SPONSOR/MONITOR'S ACROYNM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release: Distribution Unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report documents the Maneuvering and Seakeeping Basin wavemaker performance from 2004 to 2007. This report contains benchmark wave cases for comparison with future evaluations of the wavemaker performance. Fifteen data sets were examined for wave amplitude and frequency variability due to spatial position, season, and wavemaker repairs. Wave amplitude variability from wave cycle-to-cycle and between runs was also quantified. Excel macros were developed to aid future comparisons.

15. SUBJECT TERMS
waves

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE	UNCLASS	69	Timothy C. Smith
UNCLASS	UNCLASS	UNCLASS			19b. TELEPHONE NUMBER *(include area code)* 301 227-5117

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

This page intentionally left blank.

CONTENTS

FIGURES

TABLES

ABSTRACT

This report documents the Maneuvering and Seakeeping Basin wavemaker performance from 2004 to 2007. This report contains benchmark wave cases for comparison with future evaluations of the wavemaker performance. Fifteen data sets were examined for wave amplitude and frequency variability due to spatial position, season, and wavemaker repairs. Wave amplitude variability from wave cycle-to-cycle and between runs was also quantified. Excel macros were developed to aid future comparisons.

ADMINISTRATIVE INFORMATION

This work was funded with in-house overhead funding. Seakeeping Division Personnel performed the work from February to June 2007. The work unit number was 99-1-5013-024-14.

BACKGROUND

The Maneuvering and Seakeeping (MASK) Basin wavemakers were installed when the MASK was built in 1962. The wavemaker domes were refurbished in 1992. MTS controller computer boards were tuned and repaired as needed by in-house technicians. A new electronic blower controller was installed in October 2005. The MTS controller upgrade began in early April 2006.

Stahl [1,2][*] fully documents the pneumatic wavemakers at the Carderock Division, and has drawings and specifications of the MASK wavemakers. The waves were initially surveyed in 1964 by Foster [3] as part of the wavemaker set up process. Smith [4,5] surveyed the waves again in 1999 as part of the Mobile Offshore Base (MOB) testing.

The MASK wavemakers generate waves using a pneumatic system to blow air into the wavemaker dome, which forces water out of the dome and into the basin as a wave. A computer controlled flap controls airflow into the dome or vents air from the dome. Each dome has a dedicated blower motor and flap controller. The long bank, or A bank, of wavemakers is on the north side of the basin and consists of 13 domes. The short bank, or B bank, of wavemakers is on the west end of the basin and consists of 8 domes. The domes are numbered consecutively starting in the northeast corner of the basin. So Domes #1-13 are the long bank, and Domes #14-21 are the short bank. Presently the corner domes, i.e., Domes #1, 13, 14, and 21, are disabled.

There are presently six acoustic wave probes mounted along the length of MASK bridge. Previous wave surveys used these locations plus two more, for eight wave probes total. The probes are on arms extending from the bridge. Table 1 has the probe locations referenced from southeast corner of the MASK, as used in References 4 and 5.

Figure 1 shows the bridge probe locations in the MASK facility with the bridge at 0 and 30 degrees to the long bank wavemaker. The orientation of Figure 1 is rotated 180

---

[*] The complete reference list is on page 60.

degrees from that of the MASK drawings in Stahl[1,2]. Probes #2 and #7 are no longer installed.

Table 1. Bridge probe locations referenced to south-east corner (Reference 3).

Probe	Bridge= 0 X (m)	Y (m)	Bridge=30 X (m)	Y (m)
1	5.88	29.57	8.74	54.23
~~2~~	~~5.94~~	~~39.65~~	~~13.83~~	~~62.94~~
3	32.55	29.75	31.92	41.06
4	36.36	39.65	40.18	47.73
5	56.66	29.57	52.71	28.84
6	60.69	39.59	61.21	35.52
~~7~~	~~87.05~~	~~29.57~~	~~79.03~~	~~13.65~~
8	78.73	39.59	76.84	26.49

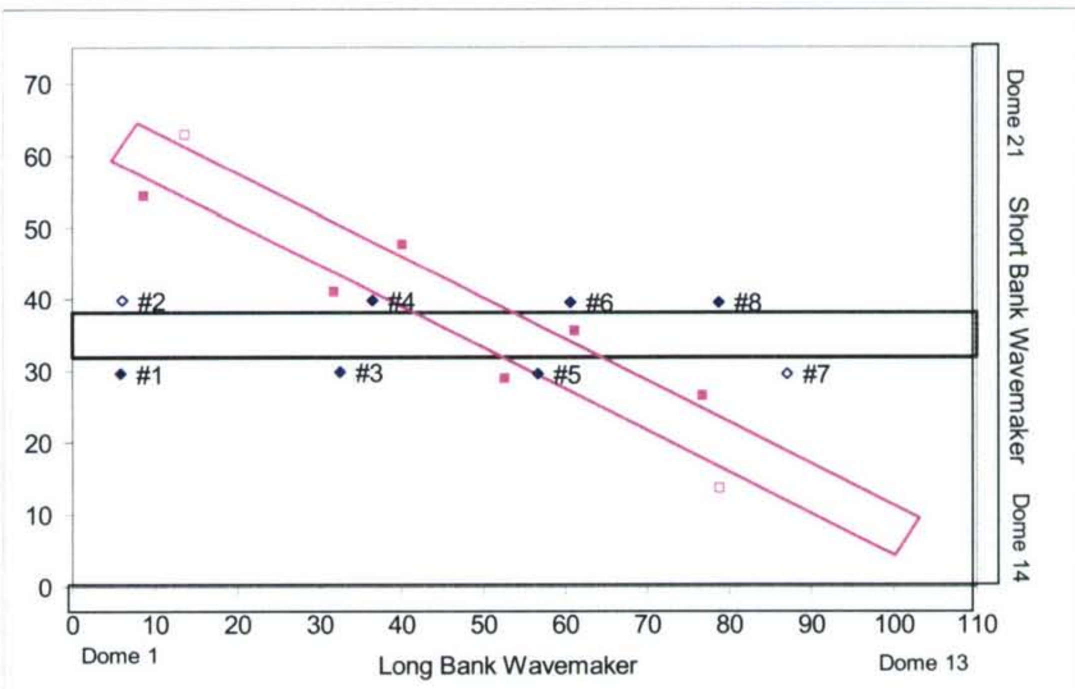

Figure 1. Probe location with bridge at 0 and 30 degrees to long bank wavemaker in Maneuvering and Seakeeping Basin (MASK).

WAVE GENERATION

The actual waves generated are the result of a complex combination of many factors. There are six devices that directly affect the wave amplitude: computer controlled flap, blower butterfly valve, span voltage, stabilizer lips, dome doors, and blower speed. Additionally, the waves are thought to be subject to environmental effects.

The computer controlled flap mechanism controls the frequency of the waves by regulating airflow into and out of the dome.

The blower butterfly valve is located in the main air duct from the blower motor to the dome. These valves have been set and welded in place. If one dome is not producing waves, i.e., a "hole in the waves", usually the butterfly valve has broken free and is shut.

The span voltage sets the stroke on the flap mechanism. It should be set to 10 volts for a maximum signal. Values higher than 10 volts, result in clipping the tops of the waves. Voltages less than 10 volts result in smaller amplitude waves. Sometimes the span voltage is reduced to avoid hitting the flapper ram on the mechanical stops in high frequency waves. This is more of a concern with irregular seas generations and the *WAVMSTR1C* program provides the option to reduce span voltage. *WAVMSTR1C* is a DOS program that generates an external signal to the wavemaker for irregular seas generation.

The stabilizer lips adjust the lip depth of the dome and act as a low pass filter. The full up position is nominally 9.5-in lip submergence and full down is nominally 22-in lip submergence. Stabilizer lips are generally set either full up or full down, though intermediate values can be specified.

Dome doors are only on the short bank domes and are interior to the dome. They close off 40-80% of the dome opening to aid higher frequency wave generation. These flaps were mechanically problematic and of limited effectiveness. They are fixed in the open position.

WAVE MEASUREMENT

Wave elevation is measured using either capacitance or acoustic probes suspended from the carriage or bridge. The 1964[3] and 1999[4,5] surveys used capacitance probes suspended from the bridge. The bridge probes were converted to acoustic probes in 2003. Carriage tests use one to three acoustic probes fixed to the carriage.

The acoustic probes measure an acoustic return off the water surface and calculate the distance between the probe and water. When the calm water distance is removed, the result is the wave elevation. The sign of the calibration is reversed so that a positive value indicates a peak, i.e., water surface closer to the probe.

The acoustic energy leaves the probe in a cone shape. The returning acoustic energy needs to hit the senor head to register a reading. The probe height above the water was chosen to minimize the risk of wave slap and model collision. Steep waves can reflect the return away from the probe causing a dropout. Signal dropouts are handled by keeping the previous value until the signal is regained. As dropouts typically occur after a peak, the effect is to increase the measured wave height root mean square. Figures 2 and 3 show wave time histories with and without dropouts.

Wave height probes were calibrated relative to a calm water surface. This was accomplished by collecting data for each probe while supported at pre-set locations as determined by location pins spaced from –15 to +15-in (-381 mm to +381 mm) in 5-inch

(127 mm) increments above and below mean level on the gage staff. The estimated manufacturing tolerance of the pin locations was ±0.005 inch (±0.127 mm).

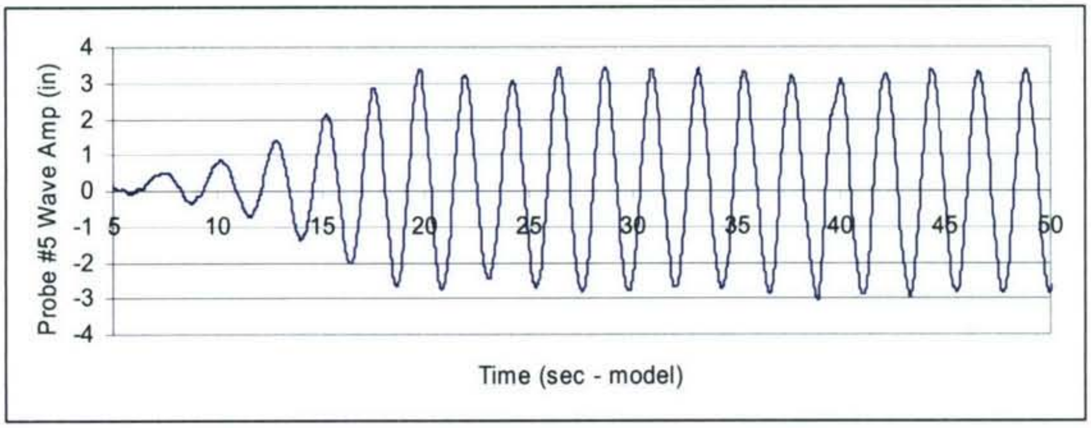

Figure 2. Wave time history for Probe#5 at 1/60 waves – initial transient.

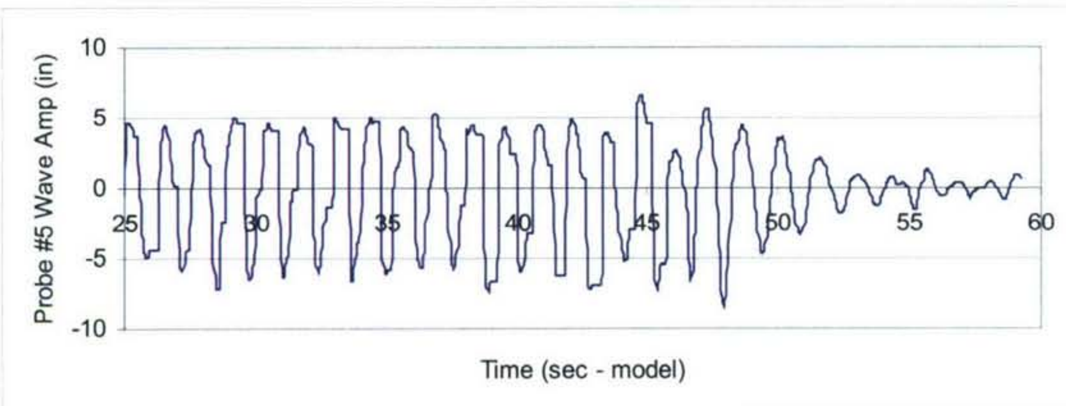

Figure 3. Wave time history for Probe#5 at 1/10 waves – ending transient.

REGULAR WAVE ANALYSIS

Test engineers used the LabView based program *WaveAnalysis_R0* (v3.2 2/2007) to harmonically analyze the majority of the wave data. The results are the first three harmonic amplitudes and frequencies for each probe as well as a "goodness metric" A1/RQ0. A1/RQ0 is the ratio of the first harmonic amplitude to the theoretical amplitude of a sine wave based on the root mean square (RMS) of the time history, i.e., 1.41*RMS. An A1/RQ0 value of 1.0 indicates a perfect sine wave.

The test engineer selects a data window for each probe, trying to select full cycles. Typically, waves after the first 4-5 transient waves and before reflection corruption are selected. Areas with dropouts or other anomalies are also avoided.

WaveAnalysis_R0 calculates the first three harmonic amplitudes and frequencies for each probe. The calculations are done using a spectral method, rather than curve fitting, which is why selecting full cycles is important to calculating the correct frequency as this reduces Fast Fourier Transform (FFT) window aliasing. The test engineers save the results to a text file, along with other pertinent information, e.g., blower speed.

Selected runs were additionally analyzed using a simple trough-to-peak analysis; and harmonic analysis with *HARMON01*, the predecessor to *WaveAnalysis_R0*. The simple trough-to-peak analysis searches for maximum and minimum points along each wave to compute period between successive peaks, and the height from trough-to-peak. Generally, 20 to 30 cycles are averaged to obtain: average period and wave height and percent variability for each gage individually and among all probes. The trough-to-peak analysis resulted in slightly steeper waves compared to the other methods.

HARMON01 uses Fourier analysis on a user-specified time segment to obtain the first three harmonic wave amplitudes. The results are used to compute variability in average wave height among the probes. A1/RQ0 is also used as a "goodness metric".

WAVE BENCHMARK APPROACH

Given the many factors that affect the wave amplitude in the MASK basin, the determination of a benchmark data set requires identifying all the parameters, collecting wave data, and selecting the best set with corresponding parameters. The amount of wave data required for MASK wave height mapping is prohibitive if conducted as a single event. Fortunately, recent regular wave testing using the same frequencies for multiple tests provide the amount of data required. These data have already been harmonically analyzed as part of the test reporting to determine the wave amplitude and frequency. Only first harmonic information is tabulated.

First, fifteen regular wave data sets from 2004 through 2007 were compiled. This report examined 3091 runs total and kept 2742 runs (88.7%) for consideration after data scrubbing. Those runs represented 186 out of 342 conditions; thus keeping 54.4% of the conditions. The majority of the dropped conditions had only been run as the test engineer was trying to determine the proper blower speed. The test dates and number of runs are listed in Table 2.

The analyzed wave data were tabulated in conjunction with the test log file. The test log file provided information necessary to group the data for analysis. Each group of identical settings was statistically analyzed to determine the maximum, minimum, mean, standard deviation, and number of samples.

The data were examined for typographical errors in recording and data quality. The typographical errors were corrected if the correct value was apparent. Data quality was determined by a combination of A1/RQ0, matching goal values, and statistical merit. Data with A1/RQ0 less than 0.85 were deleted, as this threshold value retained 1/10 wave slopes, but eliminated most spurious data. Furthermore, if the measured frequency was not within 10% of the set frequency, those data were eliminated as either bad or poorly analyzed. Data with very low amplitudes, less than 1-in, indicating probe failure were eliminated. Lastly conditions with fewer than five good runs were ignored as being statistically weak.

Sixteen wave runs from October 2004 test on model 5514 were analyzed in depth focusing specifically on the steeper waves of wave height/wave length (H/λ) = 1/20, 1/15, and 1/10 at various wavelengths. This analysis examined spatial variation across the basin, frequency variation, and variation from wave cycle to cycle within a given run. The analysis was done using simple peak-to-trough, *HARMON01,* and *WaveAnalysis_R0*.

Table 2. List of regular wave data sets.

Test Date	Total #Runs	Total #Conditions	Kept #Runs	Kept #Conditions
Sep-04	262	41	223	19
Oct-04	149	29	108	9
Nov-04	22	5	17	2
Nov-04	18	7	8	1
Dec-04	239	23	214	13
Feb-05	268	25	239	13
Apr-05	200	7	197	6
Apr-05	185	25	153	11
May-05	71	11	65	6
Jun-05	90	15	78	9
Jun-05	134	11	125	6
May-06	379	40	345	24
Aug-06	347	34	307	22
Nov-06	338	37	300	24
Jan-07	389	32	363	21
Total	3091	342	2742	186

BENCHMARK SET

The benchmark set of wave conditions lists the wave settings used to generate waves and the expected wave field. Selection of the wave setting favored recent data and conditions with an abundance of data. The January 2007 data were chosen to be the benchmark data because that set had a large number of good runs and was done after all wavemaker repairs and wave calibrations were performed. There are 21 wave conditions, i.e., combinations of frequency, blower speed, and wavemaker bank. The wavemaker settings and the 95% confidence range for wave amplitudes at each probe are in Table 3. Figures 4-8 show the wave amplitude range for each condition by probe. The bridge angle is 30 degrees. The span voltage is 10.0 V.

Probe #1 is consistently an outlier compared to the other probes, especially with long bank waves. Also, the lowest frequency, 0.515 Hz, has the most spatial variation of the benchmark set and the most variation between wavemaker banks. For benchmark purposes these conditions provide information about the extremes of the wave generation system.

For comparison with the benchmark data set, the measured waves at each probe should fall within the acceptable wave height range for a given wavemaker setting. The conditions with the smallest variation, typically the middle frequencies and blower speeds, should be chosen for a reduced benchmark set. The small variation will highlight any change to the wavemaker system. Those conditions are shaded in Table 3.

Table 3. MASK wave benchmark settings and 95% confidence band limits for each probe.

				Probe 1		Probe 3		Probe 4		Probe 5		Probe 6		Probe 8	
Freq	Blower RPM	Bank	Lips	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
0.515	1340	Long	Down	3.77	4.29	7.55	8.93	4.19	5.50	5.79	7.89	4.92	5.80	4.43	5.45
0.515	1600	Long	Down	4.93	7.02	8.57	10.26	5.87	8.05	7.10	9.80	6.46	8.96	5.96	7.94
0.564	1025	Long	Up	2.28	3.33	4.68	5.65	4.28	4.98	4.38	5.23	4.66	5.11	4.53	5.43
0.564	1210	Long	Up	3.14	4.45	5.49	6.94	5.35	6.28	5.99	7.04	5.52	6.45	6.25	7.54
0.564	1600	Long	Up	4.04	6.82	6.95	9.16	7.45	9.55	7.25	8.78	6.69	8.47	8.48	10.46
0.631	955	Long	Up	2.38	2.90	3.71	4.57	3.64	4.31	3.30	4.19	3.18	3.96	3.66	4.16
0.631	1140	Long	Up	3.16	4.54	4.47	5.58	4.74	5.90	4.29	5.21	4.59	5.63	5.00	5.88
0.631	1550	Long	Up	4.31	5.66	7.25	8.42	7.43	9.15	6.73	7.66	6.74	8.22	7.02	8.13
0.728	700	Long	Up	1.70	2.09	2.27	3.85	2.30	3.04	2.60	3.27	2.38	2.87	2.46	3.10
0.728	890	Long	Up	2.57	3.16	3.52	4.67	3.39	4.23	3.33	3.93	3.61	4.05	3.72	4.23
0.728	1300	Long	Up	3.62	4.86	5.47	6.92	4.85	6.08	5.27	6.44	5.34	6.51	5.54	6.39
0.892	840	Long	Up	1.48	2.10	2.60	3.32	2.00	2.43	2.34	3.13	1.77	3.17	2.48	3.19
0.892	1190	Long	Up	2.43	3.37	3.34	4.21	3.07	4.14	3.60	4.77	3.29	4.28	3.77	4.94
0.515	1600	Short	Down	5.28	7.13	4.70	8.37	5.93	8.07	6.48	8.94	6.35	8.30	6.23	7.77
0.564	1315	Short	Up	5.07	6.31	4.60	6.73	5.88	7.08	5.71	7.48	5.76	7.17	6.61	7.45
0.564	1600	Short	Up	4.38	8.53	5.89	8.81	7.48	9.53	7.24	9.08	6.25	7.76	8.15	8.96
0.631	1165	Short	Up	3.67	5.23	3.81	5.04	4.70	5.53	5.25	6.01	4.85	5.52	5.40	6.67
0.631	1600	Short	Up	5.28	7.07	6.82	8.04	6.79	7.99	7.41	8.38	7.04	8.33	7.12	8.18
0.728	915	Short	Up	2.52	3.56	3.35	4.27	3.09	4.26	4.21	4.67	3.70	4.30	3.19	3.77
0.728	1300	Short	Up	3.28	4.95	4.63	6.47	4.28	6.32	5.12	6.03	5.38	6.43	5.33	6.58
0.892	1190	Short	Up			3.32	4.75	2.77	4.22	2.84	4.43	3.71	4.33	3.59	4.91

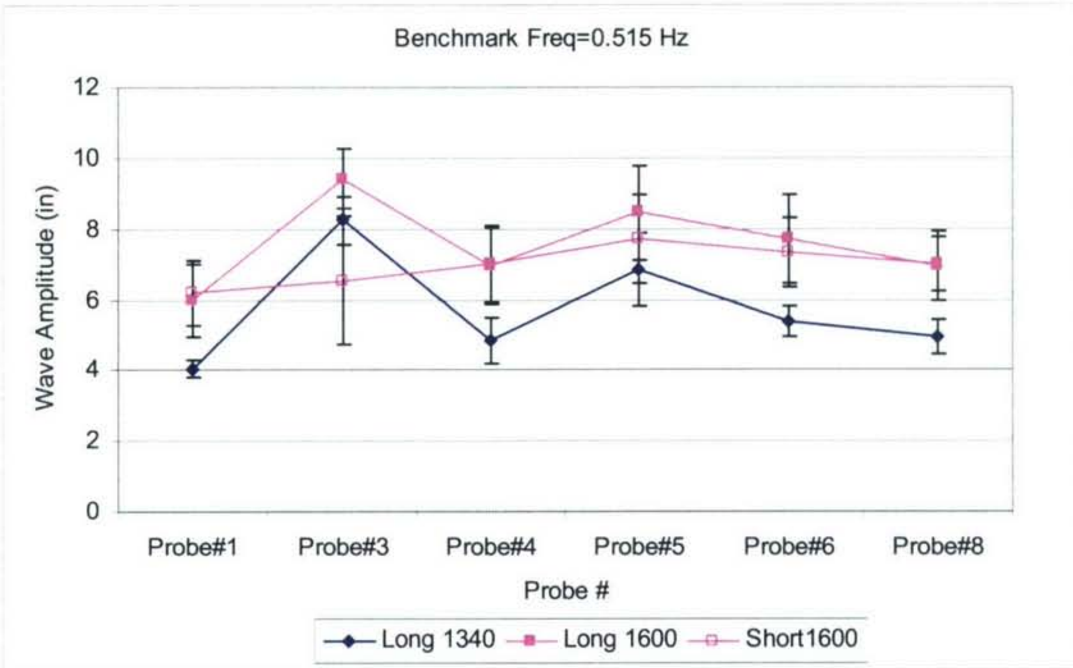

Figure 4. Expected wave amplitudes for 0.515 Hz by probe, wavemaker bank, and blower speed.

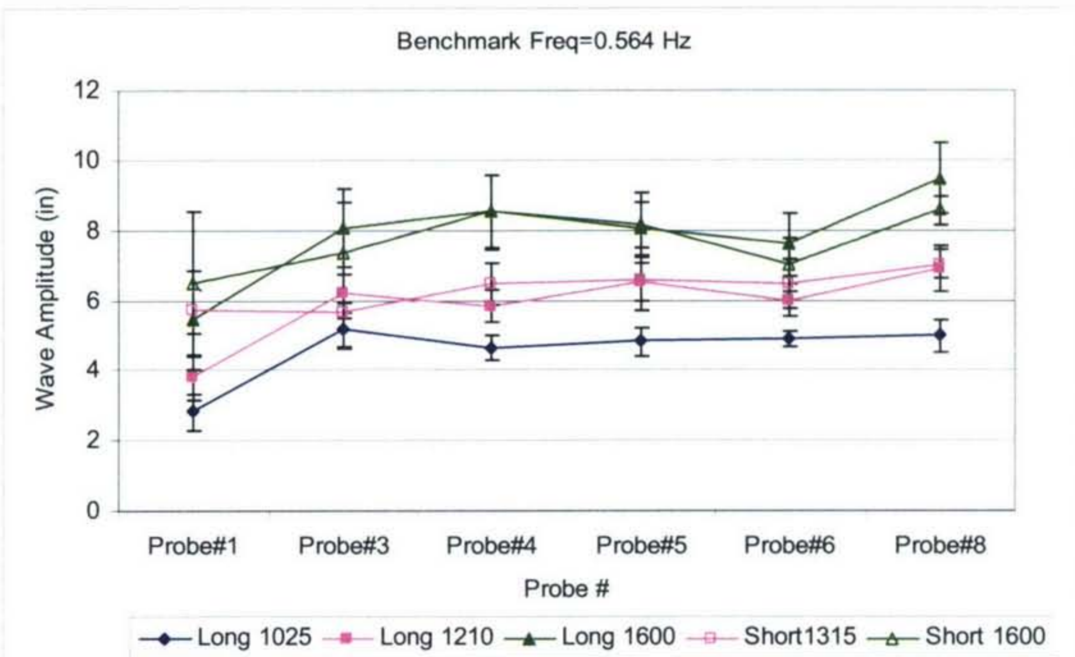

Figure 5. Expected wave amplitudes for 0.564 Hz by probe, wavemaker bank, and blower speed.

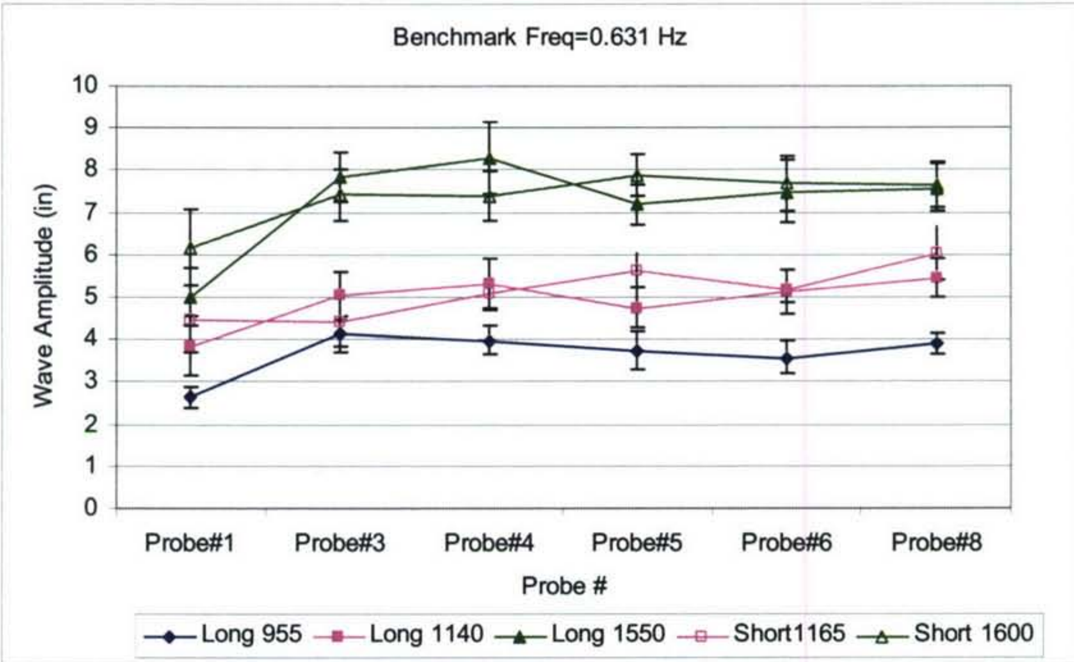

Figure 6. Expected wave amplitudes for 0.631 Hz by probe, wavemaker bank, and blower speed.

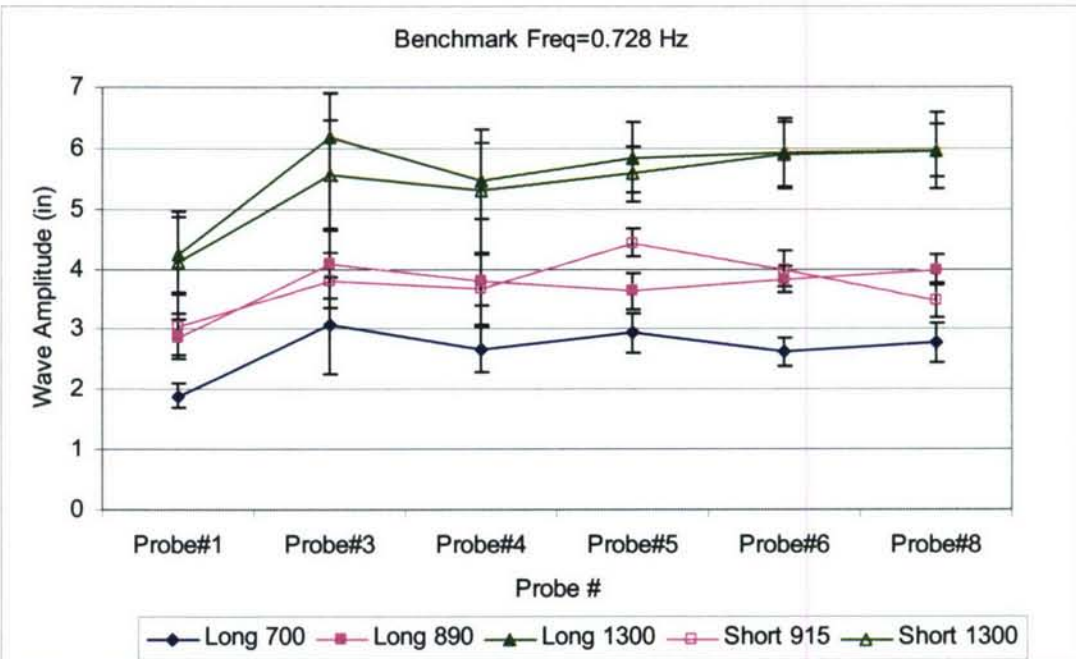

Figure 7. Expected wave amplitudes for 0.728 Hz by probe, wavemaker bank, and blower speed.

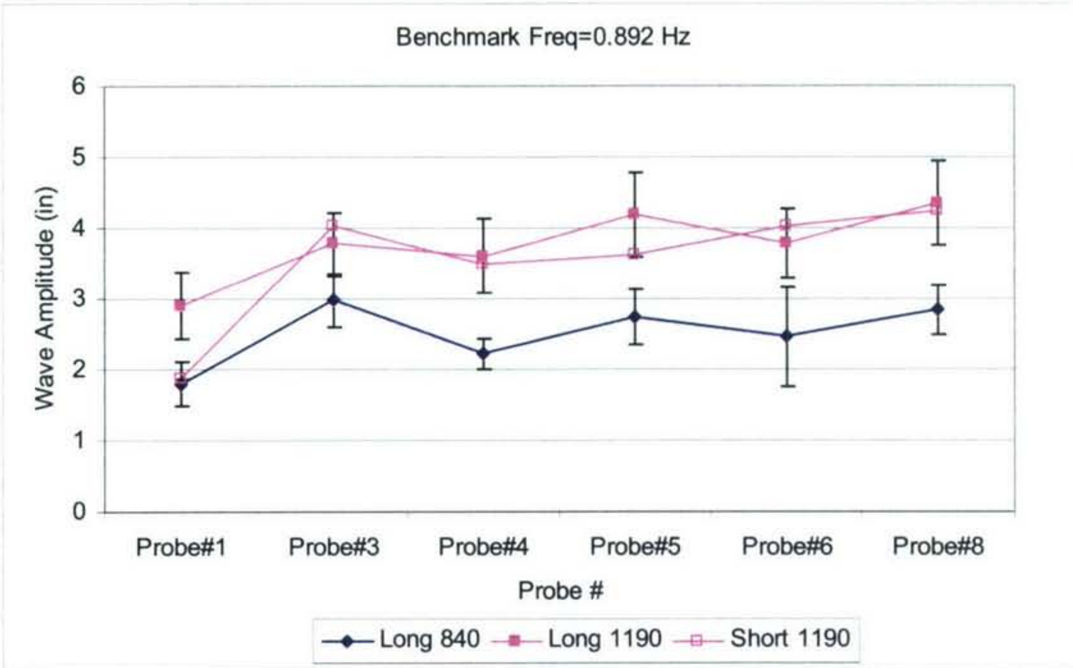

Figure 8. Expected wave amplitudes for 0.892 Hz by probe, wavemaker bank, and blower speed.

ALL DATA RESULTS

If the regular wave generation system were perfect, the measured waves in the MASK basin would all have the same frequency and wave amplitude at every measurement location. The wave crests would be uniform and parallel. Every wave cycle would have the same amplitude and frequency. The same wavemaker settings would produce the same wave field every time.

None of these are the case. Merely generating the waves from discrete domes produces a non-uniform wave field. Each dome acts as an independent radiating wave source, which when combined with the waves from the other domes produces the wave field. Theoretical predictions have shown variation in wave amplitude to approach 10% for some frequencies, simply as a result of having discrete domes.

The MASK basin sides that are perpendicular to the wave direction are a source of wave reflection and wave field distortion. The end wavemaker domes are turned off to minimize the reflection at the expense of a degraded wave field near the boundaries.

The MASK wavemakers have an initial and final transient behavior where the first and last set of waves are larger than the middle of the run. At the higher wave steepness, these waves can actually break. Furthermore, wave reflection during a run and the initial amount of water motion can cause the wave amplitude to vary within a run. Time between runs is on the order of 3-5 minutes, rather than 15-30 minutes required for the MASK basin to completely calm.

The wave settings are determined before the test and monitored during the test so they can be adjusted to attain the proper wave height. It is common to adjust the blower speed by 10-20 RPM during the test from the initial wavemaker settings. Whether this is a result of not taking enough samples when determining the wavemaker settings, environmental effects, or hydro-mechanical effects of the wavemaker system is not known.

With the data tabulated, the following questions were answered:

Is there definitive spatial variation in the MASK basin by wavemaker bank, frequency, blower speed? Are some locations always low? High?

Is there a difference in wavemaker performance by season? Is it possible to detect changes in wavemaker repair?

What is the uncertainty surrounding wave settings, frequency and blower speed, and associated wave properties? What is the repeatability of wave properties for a given wave setting? Or for a given wave property how repeatable is the wave setting?

What is the range of acceptable wavemaker performance based on A1/RQ0?

SPATIAL VARIATION

Wave height varies spatially across the basin for a variety of reasons: discrete domes, reflection, interference, and energy loss. The amount of variation also depends on wave frequency and blower speed. Over the years, the typical bridge position has moved from "zero" or parallel to the long bank to 30 degrees with respect to the long bank. The new bridge position is an attempt to locate the bridge probes near the typical model track for radio controlled model testing. The early wave surveys used the "zero" position. The data analyzed for this report use the 30 degree position. Probes #3, #4, #5, and #6 are roughly in the same location for either bridge position. With the bridge at 30 degrees, Probes #2 and #7 were removed. See Table 1 for probe locations.

To examine spatial variation, all the data were grouped by frequency, blower speed, stabilizer lip setting, and wavemaker bank. Groups contain data from more than one test. The blower speed can vary during a test as the test engineer tries to maintain acceptable waves, so blower speed was grouped into 60 RPM bins. The wave amplitude for each probe was normalized by dividing by the average wave amplitude of Probes #3, #4, #5, and #6. The normalized wave amplitudes are plotted by wave frequency, Hz, in Figures 9-14.

To interpret the normalized wave amplitude plots, the values should all be equal to one if there were no spatial variation. That is not the case. Probe #1 is always low, regardless of frequency and bank. Probe #4 data are, on average, close to the mean value, though it has greater variation than other probes. For lower frequency, long bank waves, Probes #3 and #4 are most likely to be outliers.

For both wavemaker banks, the waves are more uniform for frequencies between 0.600 and 0.800 Hz. With short bank waves, the amplitude decreases with distance from the wavemaker. This is especially true for higher frequency waves, which have more energy dissipation along the length of the basin.

Figures 4-8 have the benchmark data plotted as wave amplitude for groups of blower speed-bank groups. Similar plots from the Reference 4 and 5 wave surveys also showed similar spatial variation despite having the probes aligned parallel to the long bank. Spatial variation of the wave field is not a result of the bridge being set at an angle to the waves and not measuring the "same wave" at each probe. Appendix A has the data plotted as wave amplitude for all of the groups for comparison with plots in References 4 and 5.

Figures 4-8 are also discussed in the **AMPLITUDE VARIATION BETWEEN RUNS** section.

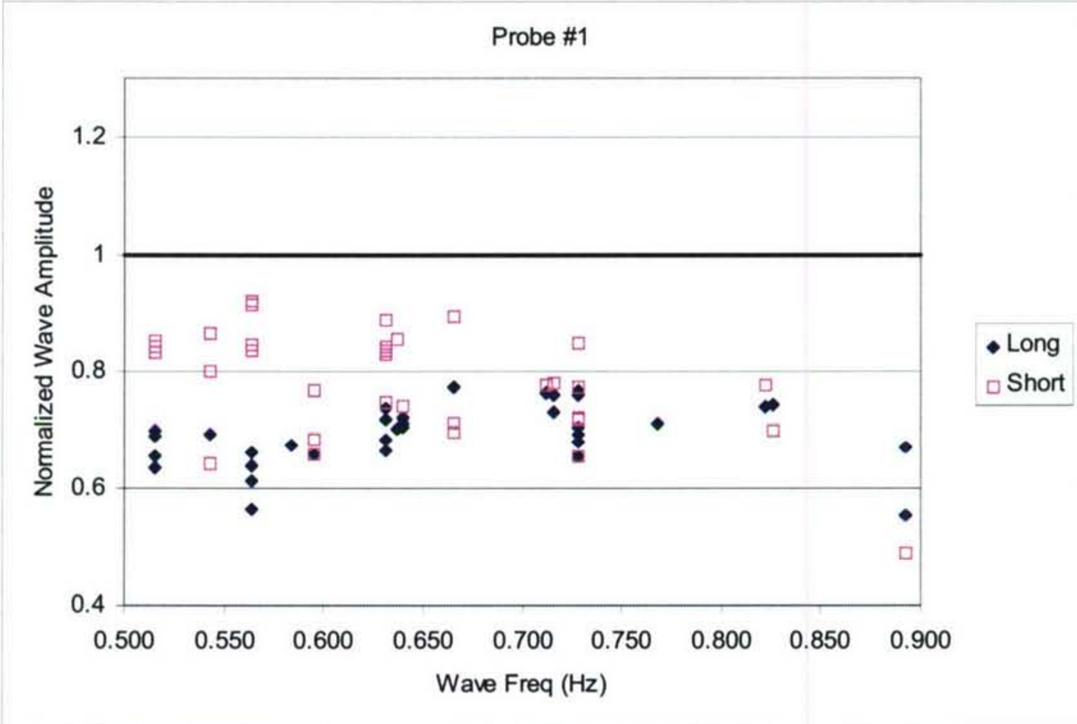

Figure 9. Normalized wave amplitude for Probe#1 by frequency and wavemaker bank.

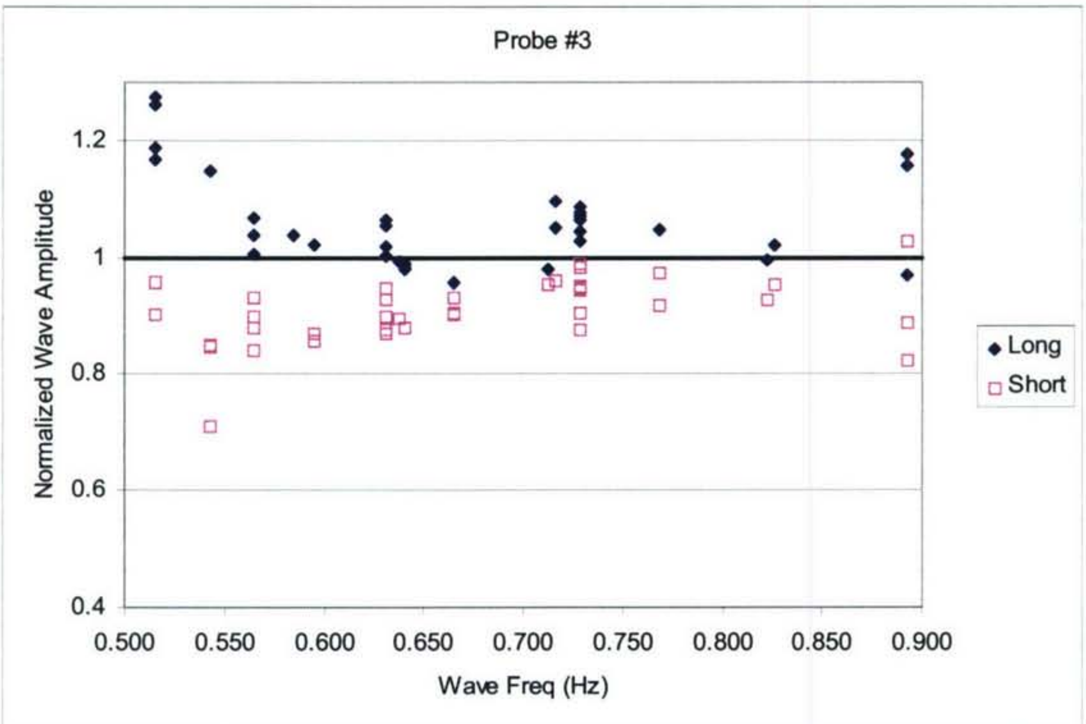

Figure 10. Normalized wave amplitude for Probe#3 by frequency and wavemaker bank.

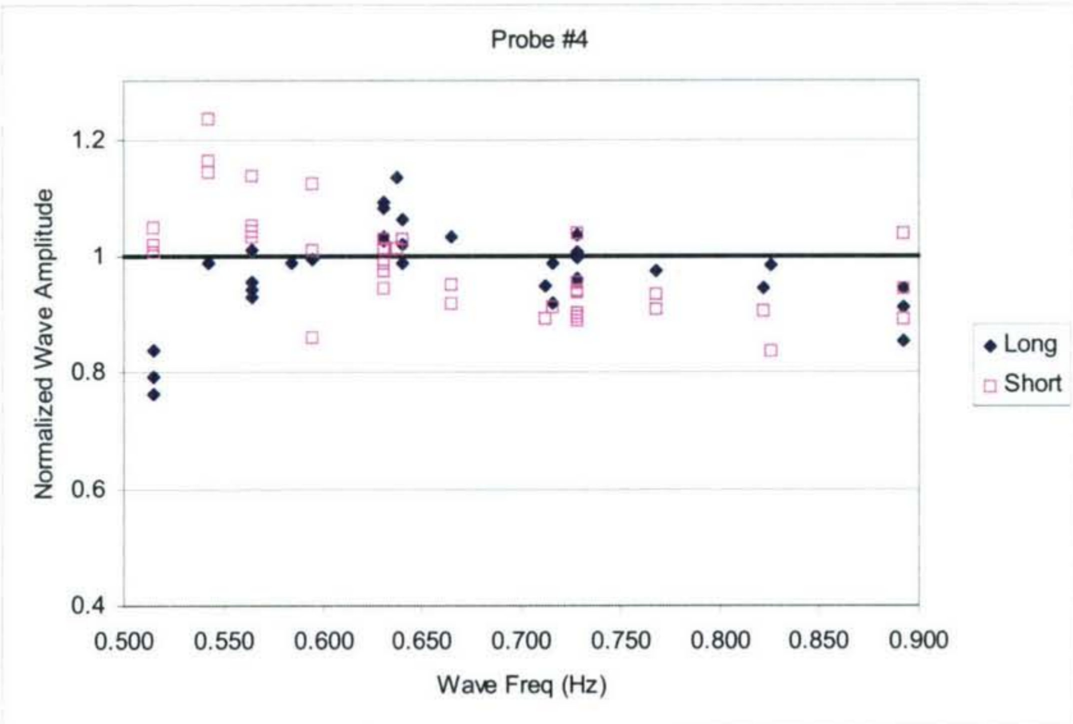

Figure 11. Normalized wave amplitude for Probe#4 by frequency and wavemaker bank.

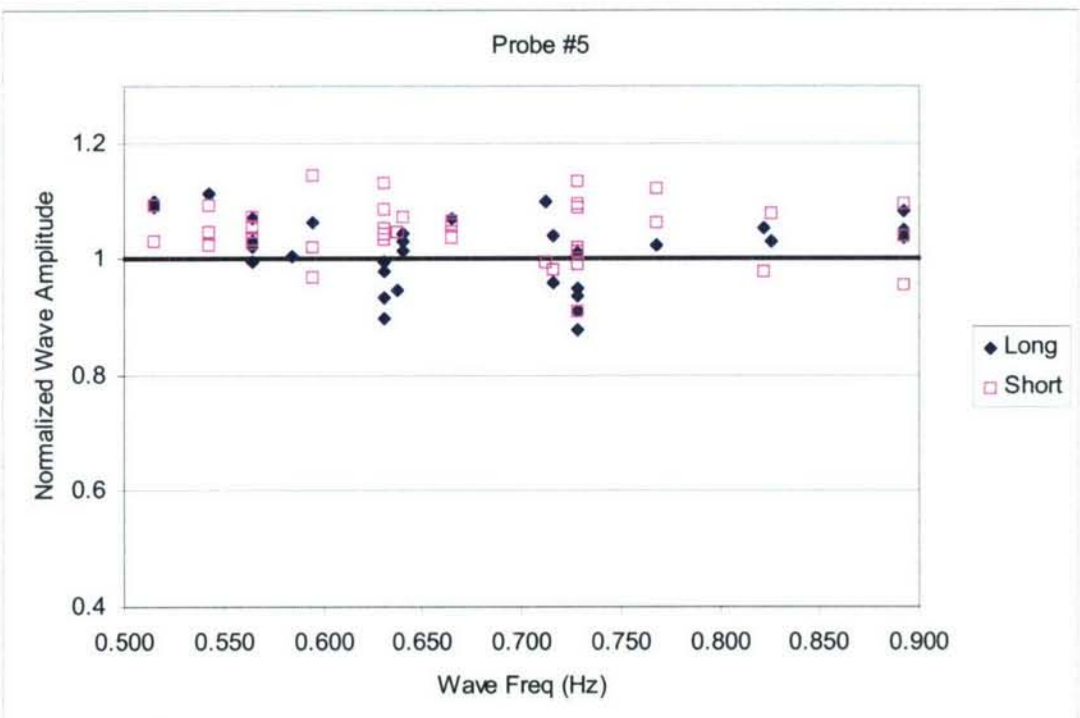

Figure 12. Normalized wave amplitude for Probe#5 by frequency and wavemaker bank.

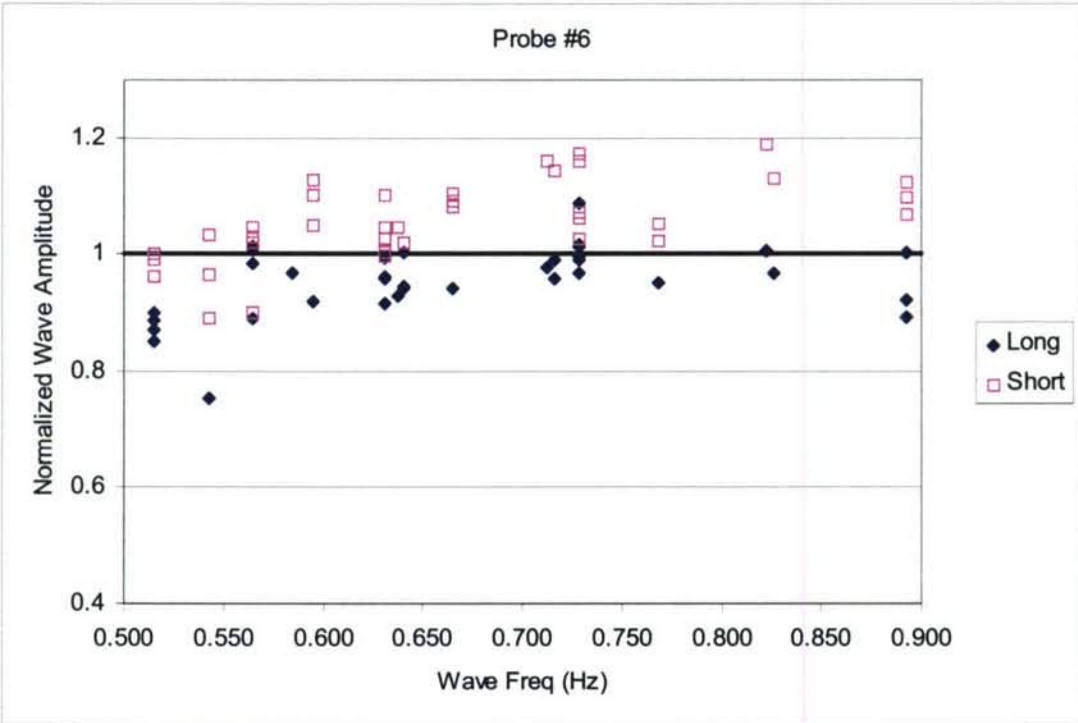

Figure 13. Normalized wave amplitude for Probe#6 by frequency and wavemaker bank.

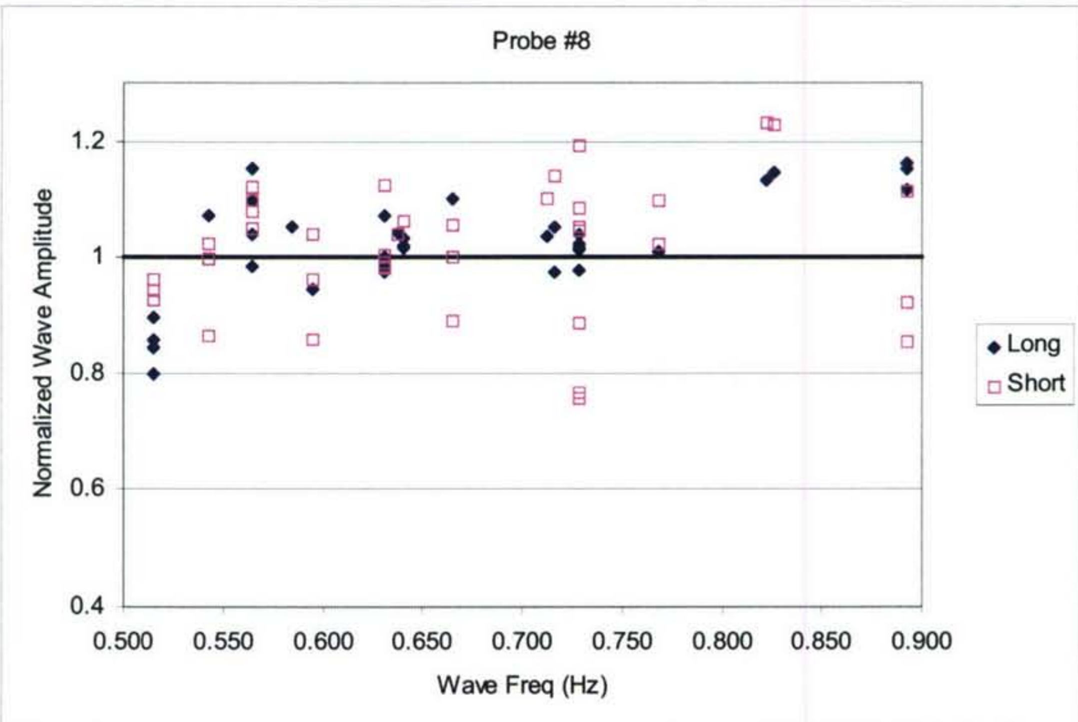

Figure 14. Normalized wave amplitude for Probe#8 by frequency and wavemaker bank.

TEMPORAL VARIATION

One of the urban legends associated with the pneumatic wavemakers is that wave amplitude or required blower speed is affected by outside temperature or pressure variations. With nearly year-round testing from 2004-2007, it is possible to investigate seasonal temperature variation effect on air density. Visual evidence of breaking waves indicates the variation due to short term air density change can be up to 4%. Additionally, by comparing data separated by years it is possible to investigate changes to the wave controller system. Pressure variation data due to short term storms are unavailable, and will remain a mystery.

The data were grouped by winter and summer seasons for each fiscal year. For instance, the winter 2005 season, Win05, is the months of October 2004 through March 2005. The summer 2005 season, Sum05, is the months of April 2005 through September 2005. Most of the testing occurred in the middle of these defined seasons. No testing was done during the 2006 winter season. Only three frequencies, 0.543, 0.634, and 0.728 Hz, were used for the whole time span, as the tested frequencies are dependent on model length. Figures 15-20 show average wave amplitude by blower speed for these frequencies.

The expectation is that the summer seasons would be close to each other and the winter seasons would be close to each other. Instead, comparing Win07, Sum06, and Sum05 data show almost constant blower RPM for a given wave amplitude for the examined frequencies and both wavemaker banks. An inconsistency is Figure 20 (0.728 Hz), where the summer 2005 data do not overlap either the winter 2007 or summer 2006 data, which are nearly identical to each other. Wave amplitude variation at maximum blower speed is more a function of measurement difficulties than seasonal variation, as shown by the large scatter at maximum blower speed.

The data do show some instances where a different blower speed is required for the same wave amplitude for the same season. This occurs between the summer 2004 season and summer 2005 season in Figures 19 and 20. It is seen within the winter 2005 season for 0.595 Hz on the short bank, Figure 21. This is most likely the result of a MTS controller board tuning which took place in January 2005. After the tuning, the required blower speed for a given wave amplitude decreased for 0.728 Hz, and increased for 0.631 and 0.564 Hz.

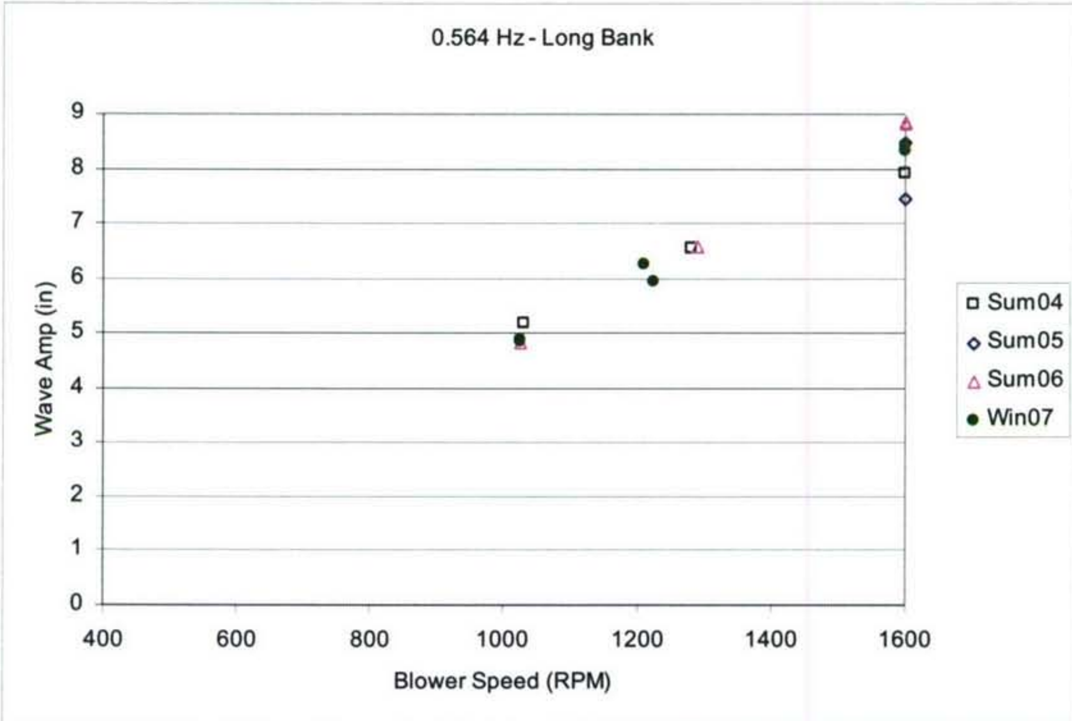

Figure 15. Average wave amplitude by blower speed and season for 0.564 Hz on long bank.

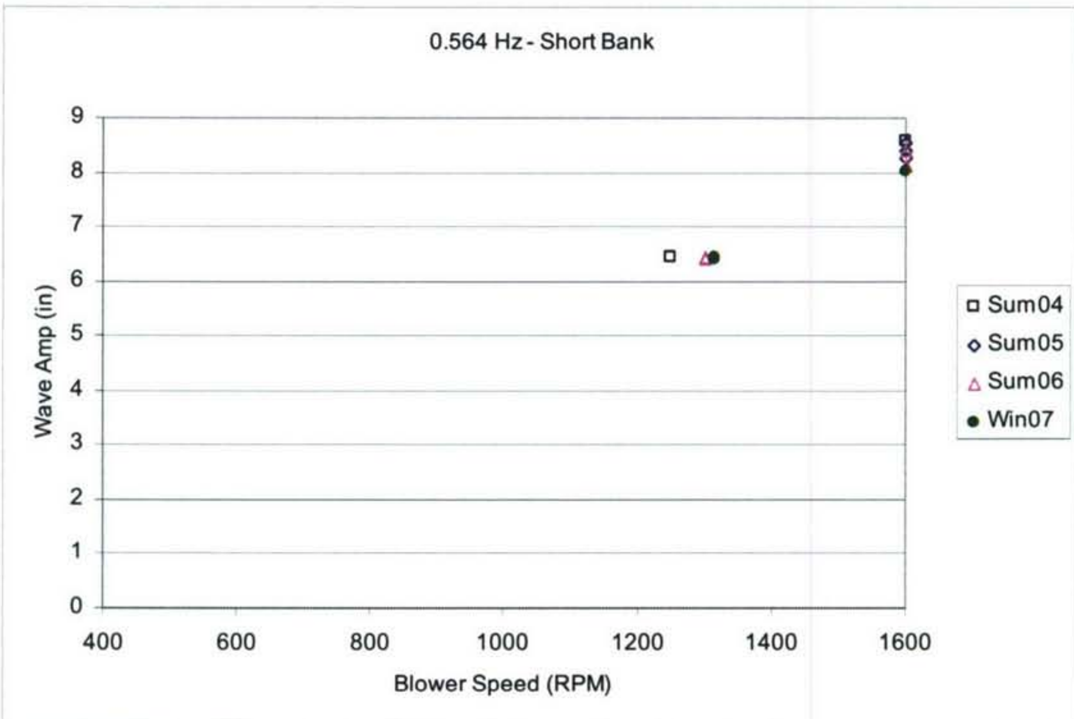

Figure 16. Average wave amplitude by blower speed and season for 0.564 Hz on short bank.

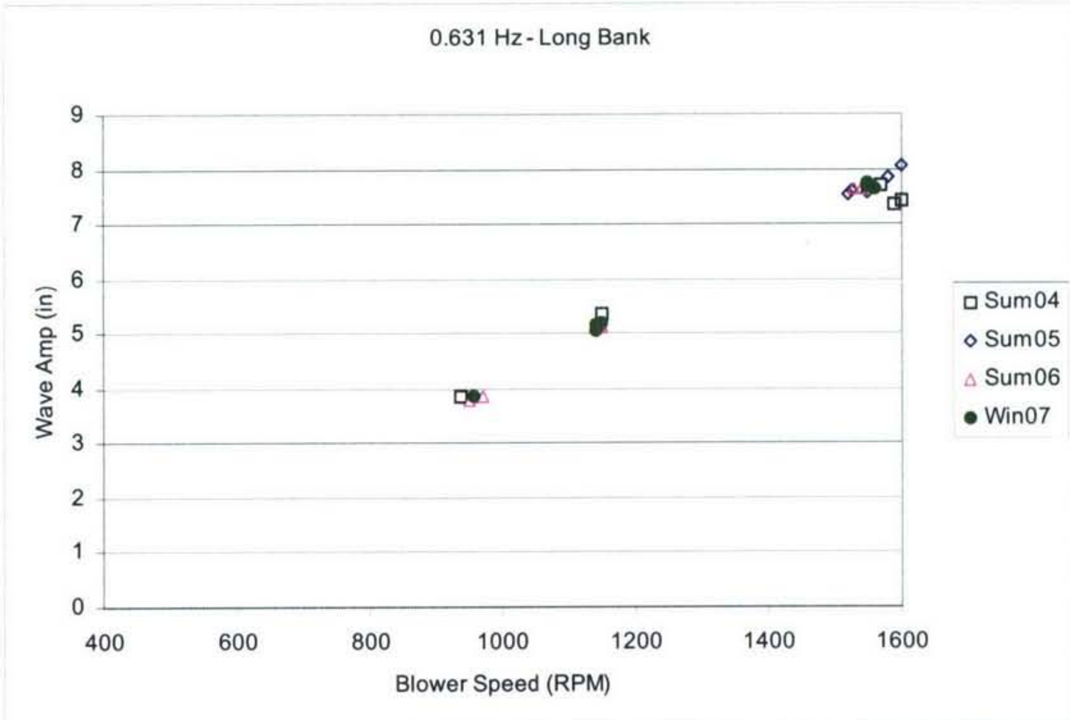

Figure 17. Average wave amplitude by blower speed and season for 0.631 Hz on long bank.

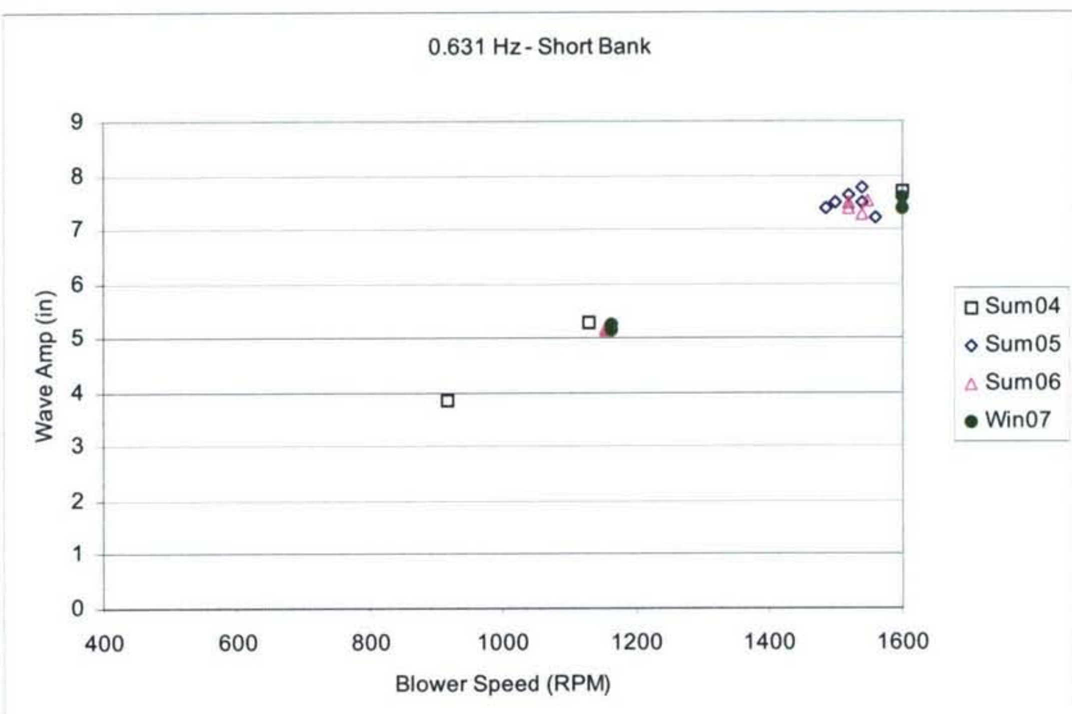

Figure 18. Average wave amplitude by blower speed and season for 0.631 Hz on short bank.

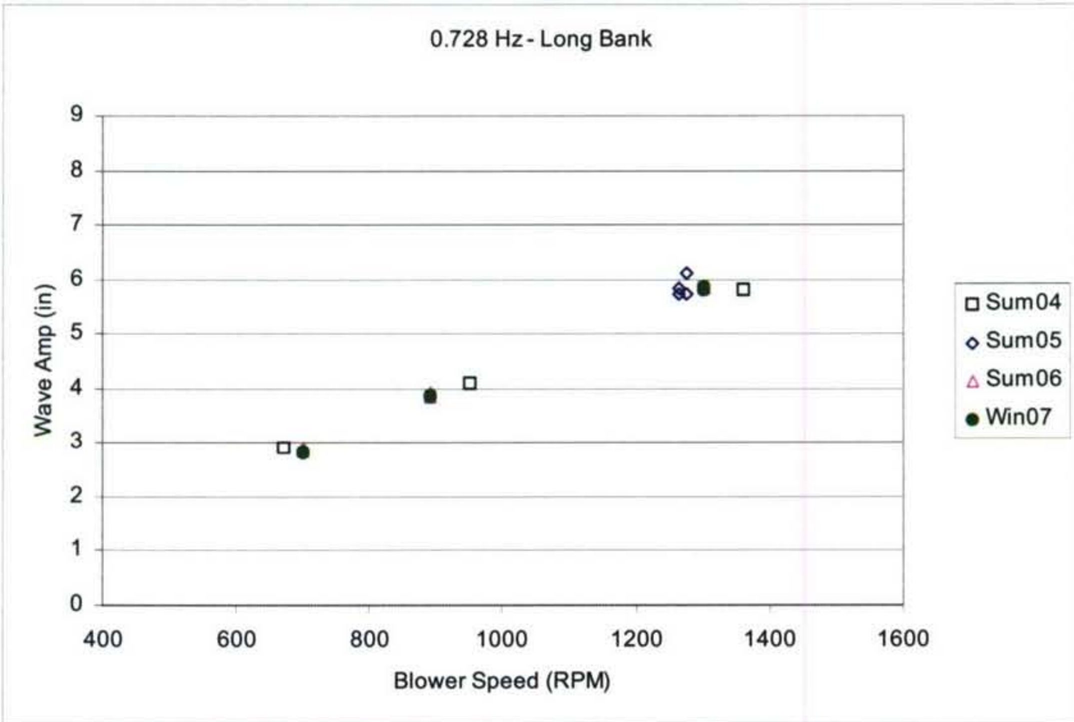

Figure 19. Average wave amplitude by blower speed and season for 0.728 Hz on long bank.

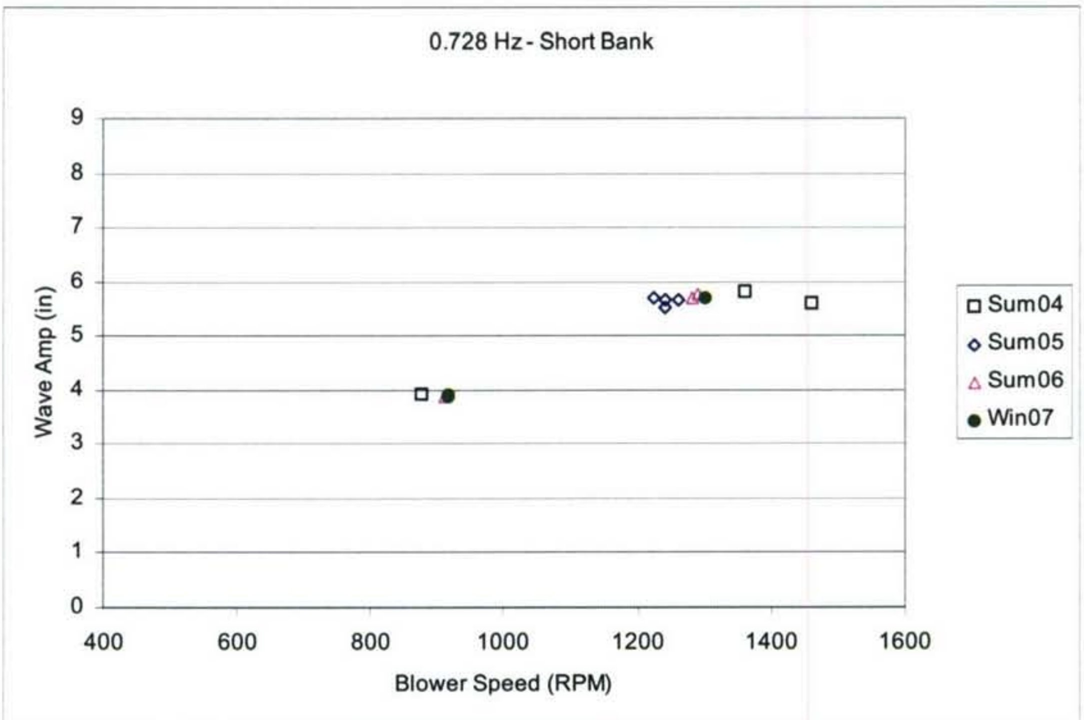

Figure 20. Average wave amplitude by blower speed and season for 0.728 Hz on short bank.

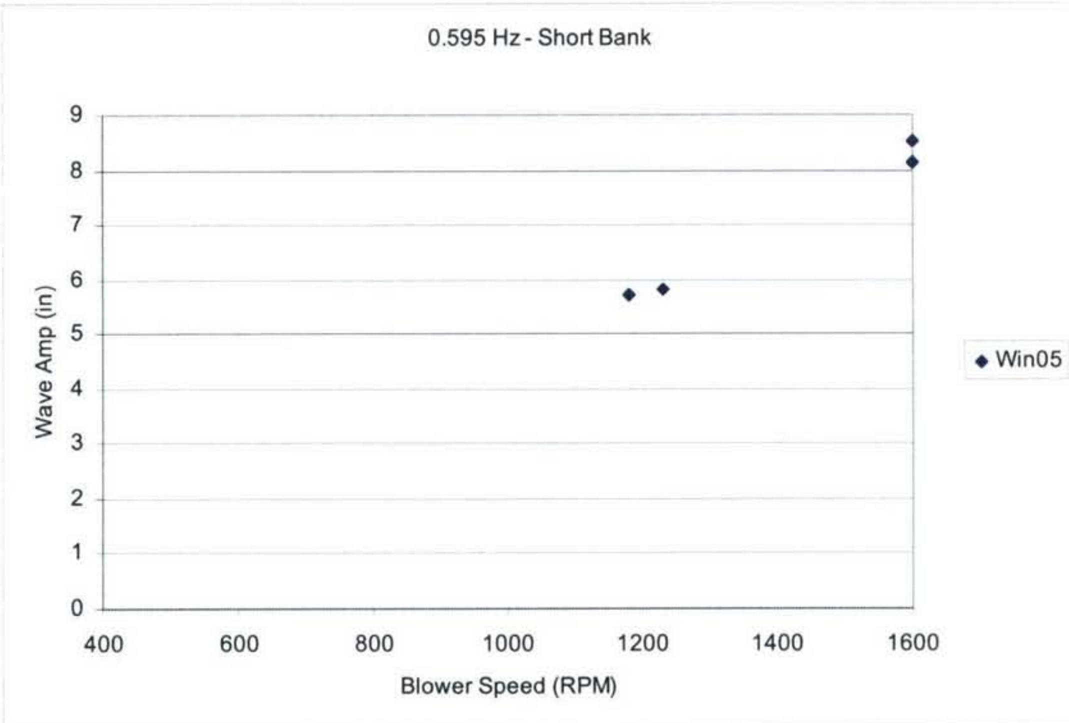

Figure 21. Average wave amplitude by blower speed and season for 0.595 Hz on short bank.

CYCLE-TO-CYCLE WITHIN RUN VARIATION

The wave amplitude can also vary from cycle-to-cycle at one probe location for a given wavemaker setting. This is primarily due to initial transients in the wave front and reflection off the beach affecting the waves. There is also second order interaction effects which are more prevalent with steeper waves. See Figure 22 for a comparison of measured waves, linear waves, and non-linear Stokes waves.

Looking at the selected 16 runs from the trough-to-peak analysis gives the variability between wave heights within a run. Table 4 compares the ratio of standard deviation of the wave heights to the average wave height for the different conditions. Ignoring Probe #1, the variation is 5% for $H/\lambda=1/20$ and 1/15. The variation is roughly 10% for $H/\lambda=1/10$. These values are consistent to what was found during the MOB wave survey in 1999 [4,5].

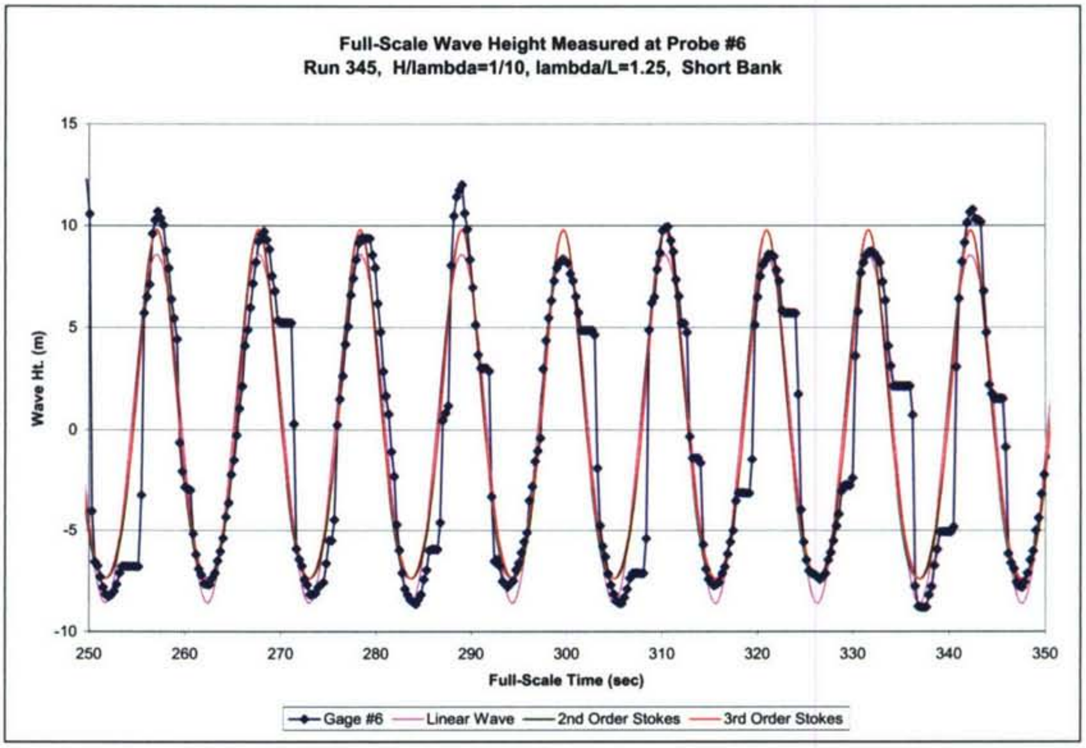

Figure 22. Comparison of measured wave and various order Stokes waves (full scale).

Table 4. Percent variation of wave amplitude within a run.

Run Number	Target H/λ	Target λ/L	Bank	Probe #1	Probe #3	Probe #4	Probe #5	Probe #6	Probe #8
307	20	1.25	Long	4.19	3.57	4.68	3.23	5.18	5.22
400	20	1.50	Long	3.28	3.99	5.70	5.03	5.53	4.20
Avg 1/20				3.73	3.78	5.19	4.13	5.35	4.71
409	15	1.50	Short	3.21	3.42	3.56	3.78	3.38	3.53
404	15	1.50	Long	3.18	9.30	3.47	3.76	4.11	4.72
317	15	1.25	Long	2.43	5.36	3.85	4.89	5.32	5.46
320	15	1.25	Short	17.12	5.09	3.58	4.14	7.03	3.40
240	15	1.00	Long	10.33	9.01	4.65	3.83	6.14	5.02
Avg 1/15				7.25	6.43	3.82	4.08	5.20	4.43
339	10	1.25	Long	5.84	6.15	4.81	7.54	5.25	4.71
342	10	1.25	Long	5.25	5.84	8.52	4.99	20.07	4.63
437	10	1.25	Long	4.52	3.98	8.25	3.86	5.98	4.84
345	10	1.25	Short	15.57	13.52	8.17	8.08	6.59	5.75
249	10	1.00	Short	18.05	18.77	10.43	17.62	12.01	6.34
278	10	1.00	Long	10.07	10.95	10.42	6.54	7.54	6.50
280	10	1.00	Long	8.54	8.73	8.04	8.58	7.44	9.83
232	10	0.75	Long	17.77	6.34	16.55	10.00	15.12	6.35
195	10	0.75	Short	35.22	19.66	19.89	17.11	11.67	10.75
Avg 1/10				13.42	10.44	10.56	9.37	10.19	6.63

FREQUENCY VARIATION

Wave frequency is controlled with a hard wired frequency generator that is an integral part of the wavemaker control system. As shown in Figure 23 for the benchmark data set, the relation of obtained frequency verses desired frequency is almost completely linear. The slight variation at higher frequencies is error due to not picking complete cycles when analyzing the data. This is magnified at higher frequencies where slight variations represent a larger portion of the cycle.

All other test data show this close correlation between set and measured wave frequency. The overall average percent error is 0.42 percent. Figure 24 shows the same linear trend for all the data considered.

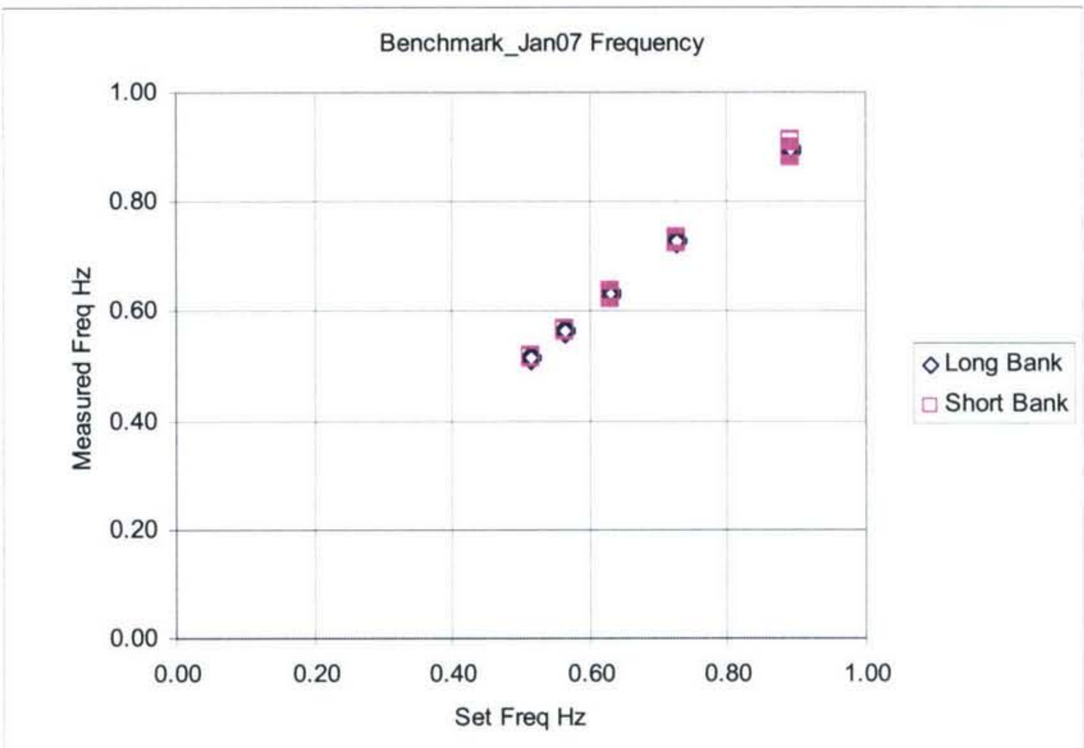

Figure 23. Benchmark measured frequency vs. set frequency.

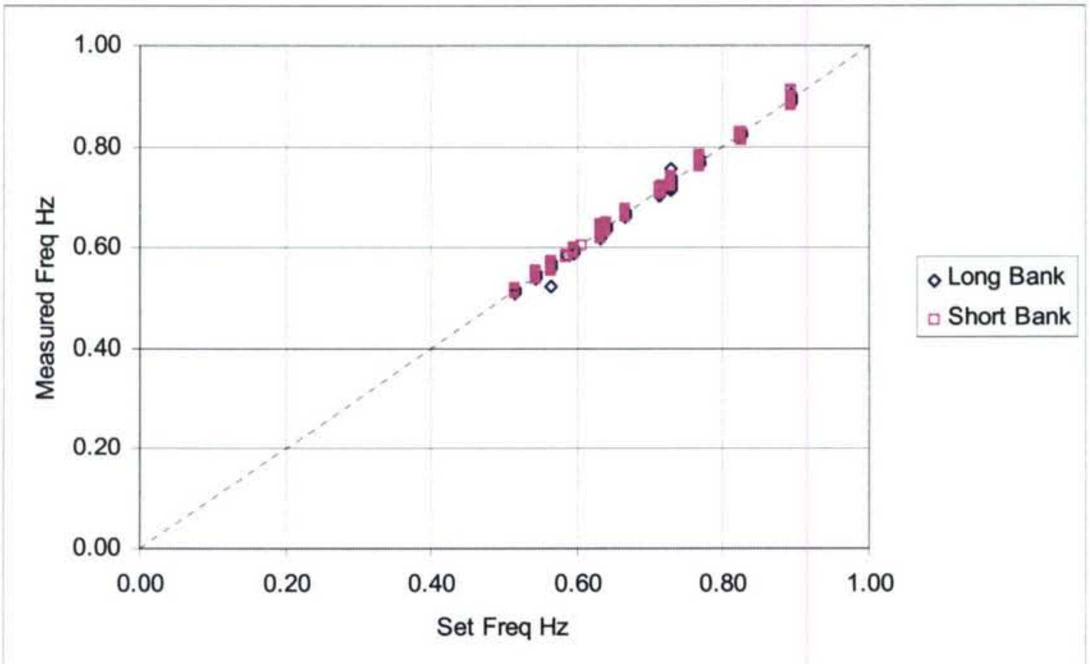

Figure 24. Measured frequency vs. set frequency for all data.

AMPLITUDE VARIATION BETWEEN RUNS

For a given wavemaker setting, the generated waves can vary from run to run. This can be due to the build up of reflection and standing waves in the basin as well as wavemaker hydraulic system fluctuations. For this reason, wave heights are monitored during a test and changes are made to the blower speed to ensure the correct wave height. Some judgment is called for in knowing when to adjust blower speed, as the fluctuations could be random, rather than systematic.

To examine the variation between runs, the standard deviation of the wave heights was divided by the average wave height for each probe for a given wavemaker setting. This ratio is known as the coefficient of variability. Those results are in Appendix B. Coefficients of variability greater than two standard deviations are shaded. Probe #1 has consistently high variability and is ignored. The average coefficient of variation of the remaining probes across all conditions is 5.81±2.13% on the long bank and 6.17±3.02% on the short bank. Generally, wave height variation of 5-6% is accepted as normal operations. If the variation reaches 10%, some action is warranted.

There are trends as to which conditions have a larger variation. For the short bank, Probe #3 has higher variability than other probes. The lowest variability occurs in for wave frequencies between 0.600 and 0.700 Hz. The run-to-run variation is largest at the steeper waves, as expected, due to the degraded quality of these waves and their measurement. Wave height variation is independent of date. Figures 4-8 show the variation using error bars for the benchmark case.

An associated question is how much to change blower speed to bring the wave height into acceptable ranges. The traditional rule of thumb is one inch per 100-RPM, though Table 5 shows this to be high. Average wave height varies from 0.4 to 0.8 inches per 100 RPM. More accurately, this number will vary with respect to frequency and blower speed (RPM). The variation with respect to blower RPM is small as shown by the relatively linear trends seen in the Figure 25-36 scatter plots.

Table 5. Blower speed per inch by frequency and wavemaker bank.

Freq Hz	Long Bank		Short Bank	
	in/100 RPM	RPM/in	in/100 RPM	RPM/in
0.515	0.78	128	0.7	143
0.564	0.57	175	0.56	179
0.631	0.63	159	0.56	179
0.728	0.49	204	0.47	213
0.891	0.37	270	0.36	278

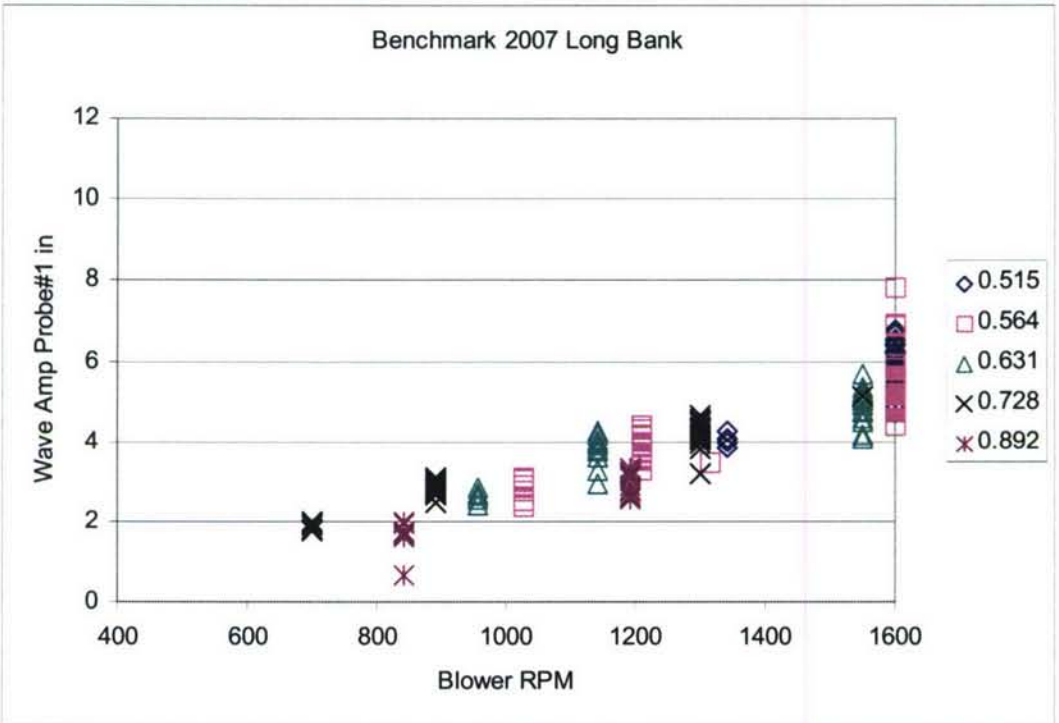

Figure 25. Benchmark Probe#1 wave amplitude variation by frequency for long bank.

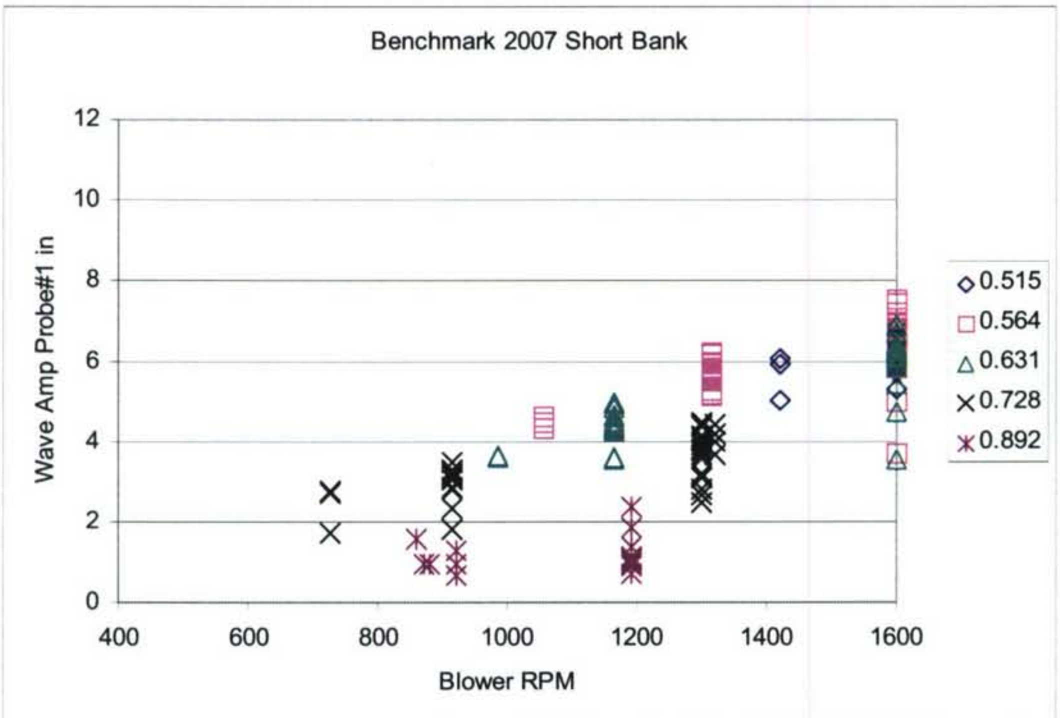

Figure 26. Benchmark Probe#1 wave amplitude variation by frequency for short bank.

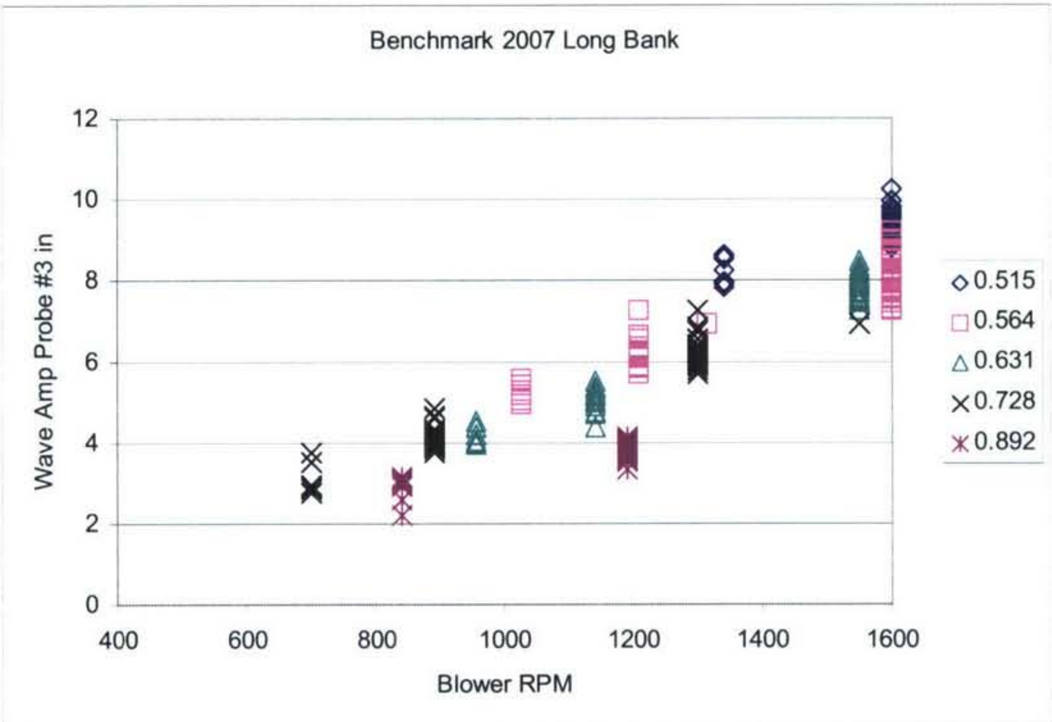

Figure 27. Benchmark Probe#3 wave amplitude variation by frequency for long bank.

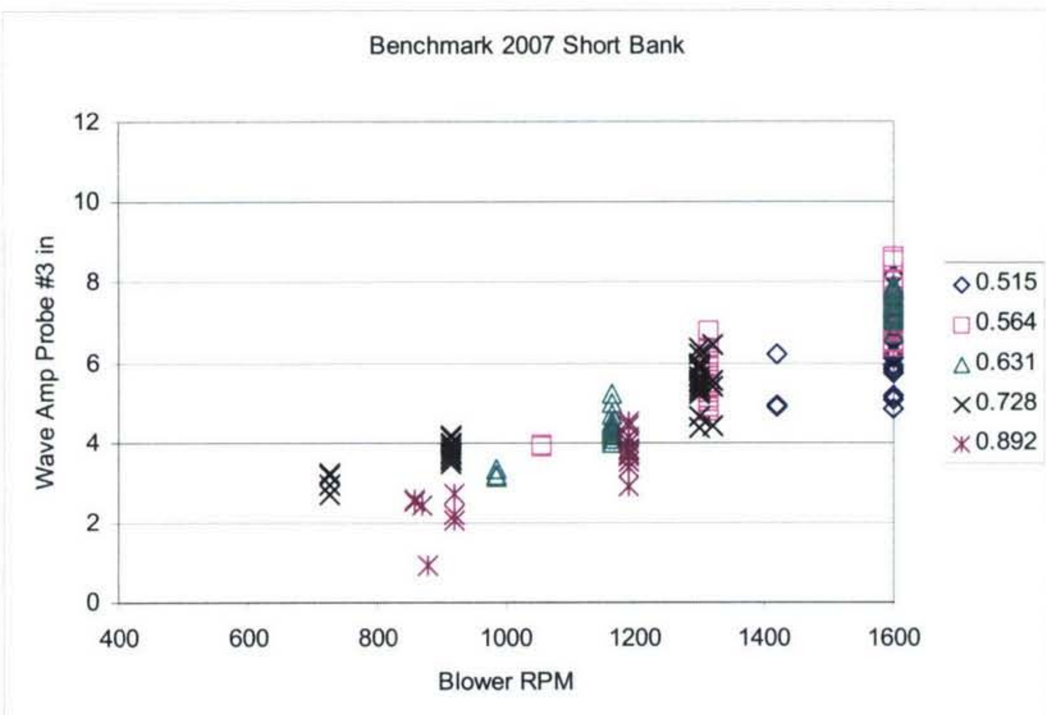

Figure 28. Benchmark Probe#3 wave amplitude variation by frequency for short bank.

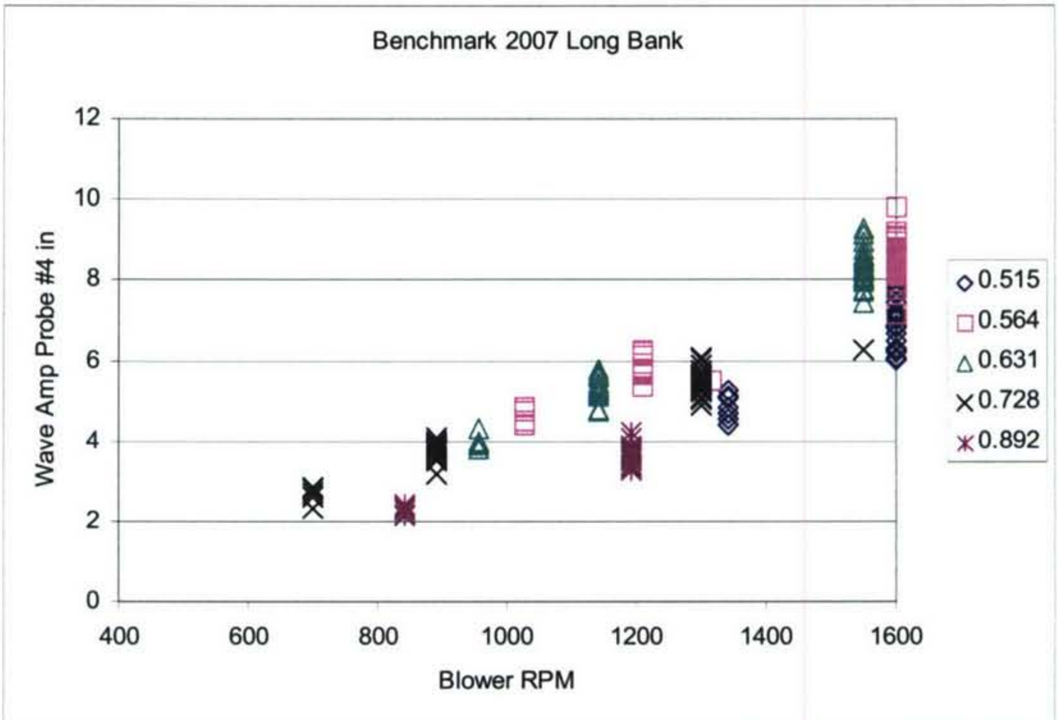

Figure 29. Benchmark Probe#4 wave amplitude variation by frequency for long bank.

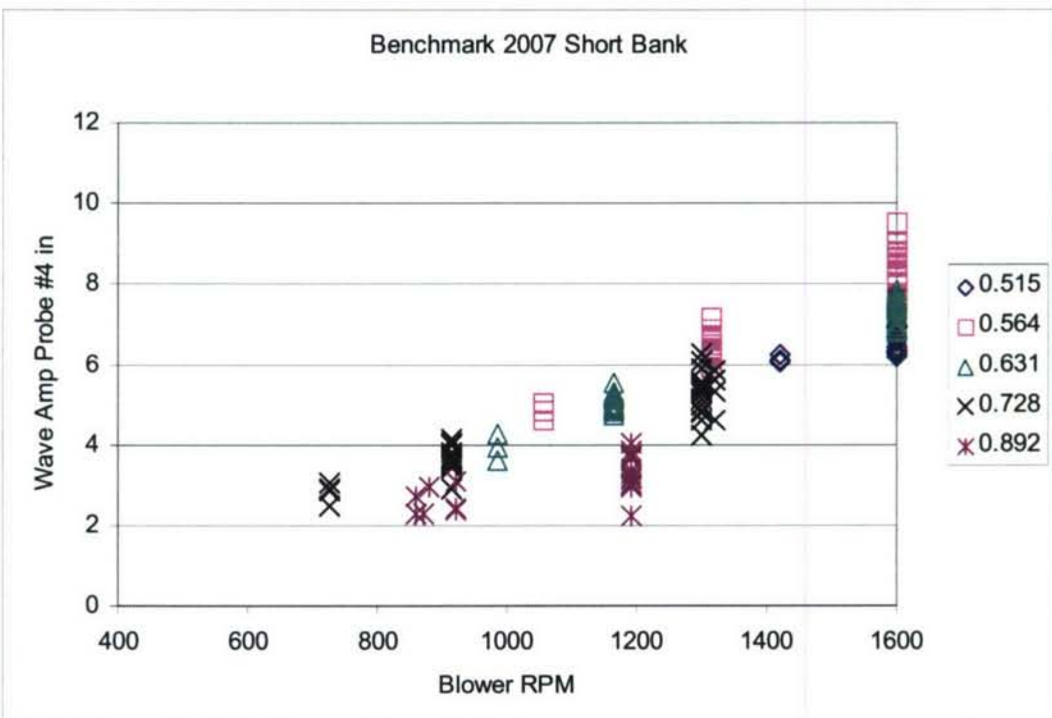

Figure 30. Benchmark Probe#4 wave amplitude variation by frequency for short bank.

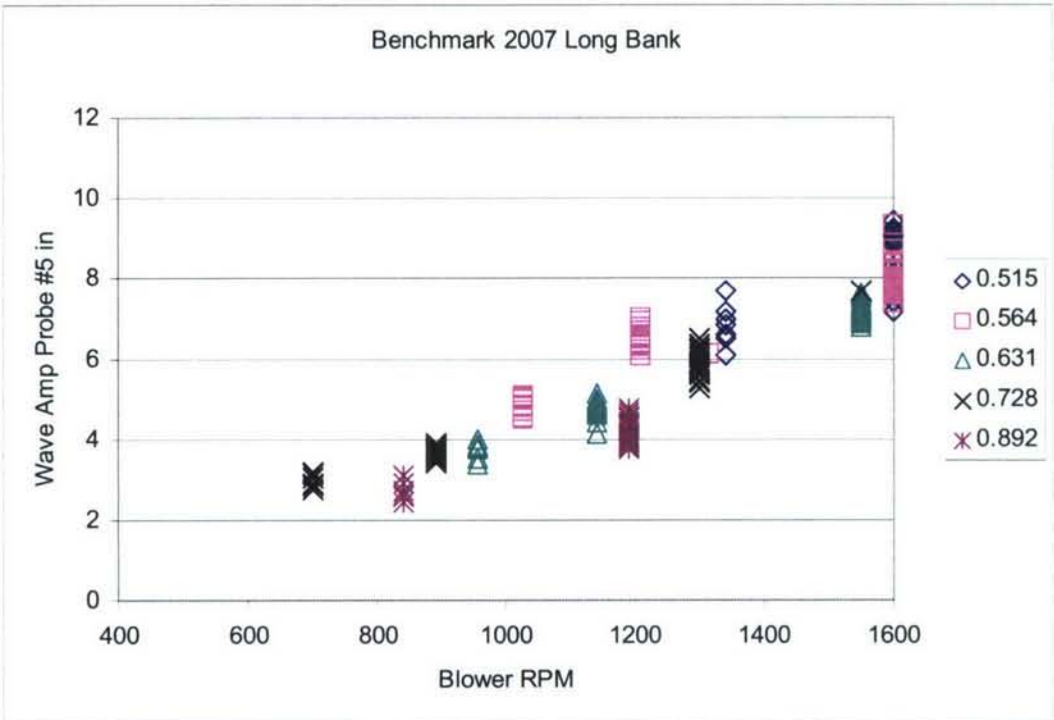

Figure 31. Benchmark Probe#5 wave amplitude variation by frequency for long bank.

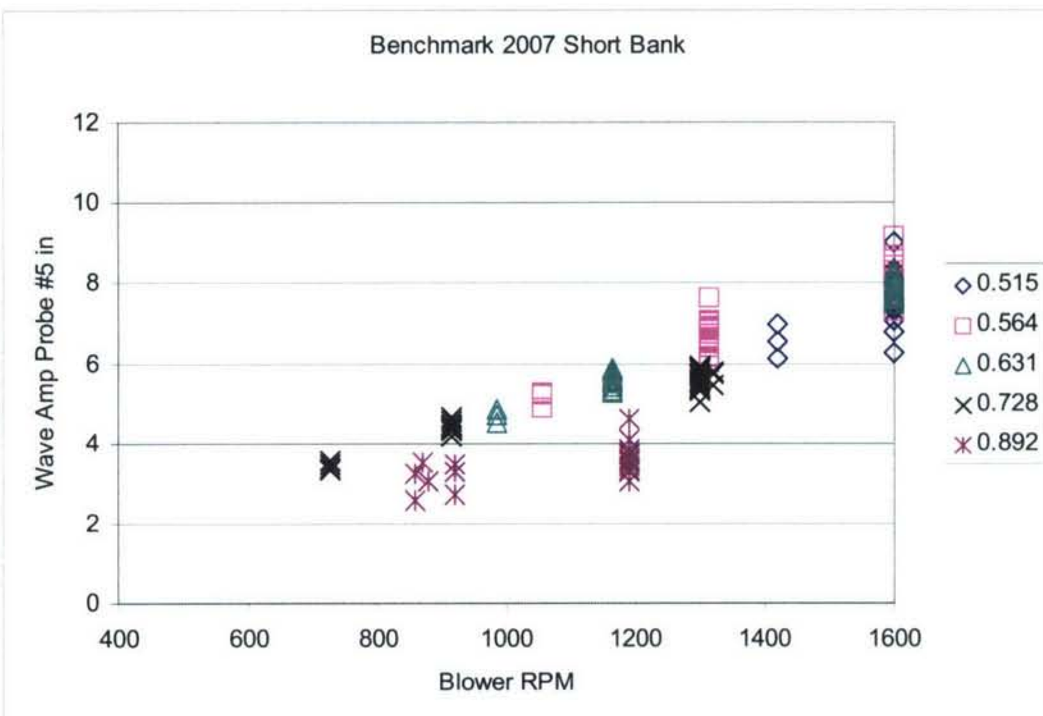

Figure 32. Benchmark Probe#5 wave amplitude variation by frequency for short bank.

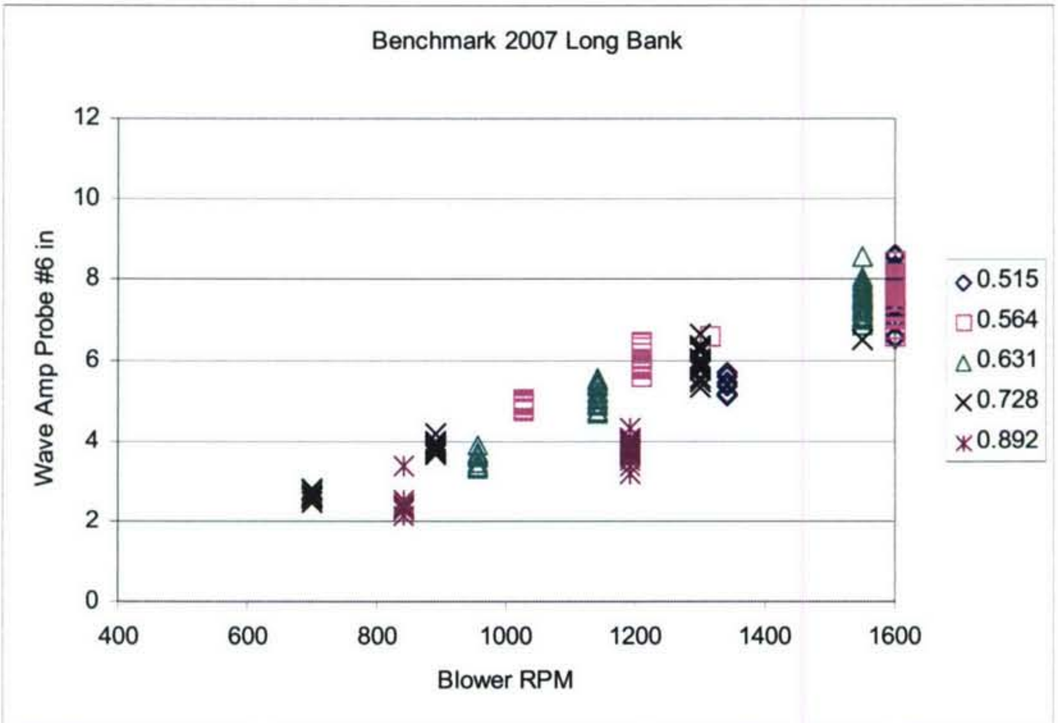

Figure 33. Benchmark Probe#6 wave amplitude variation by frequency for long bank.

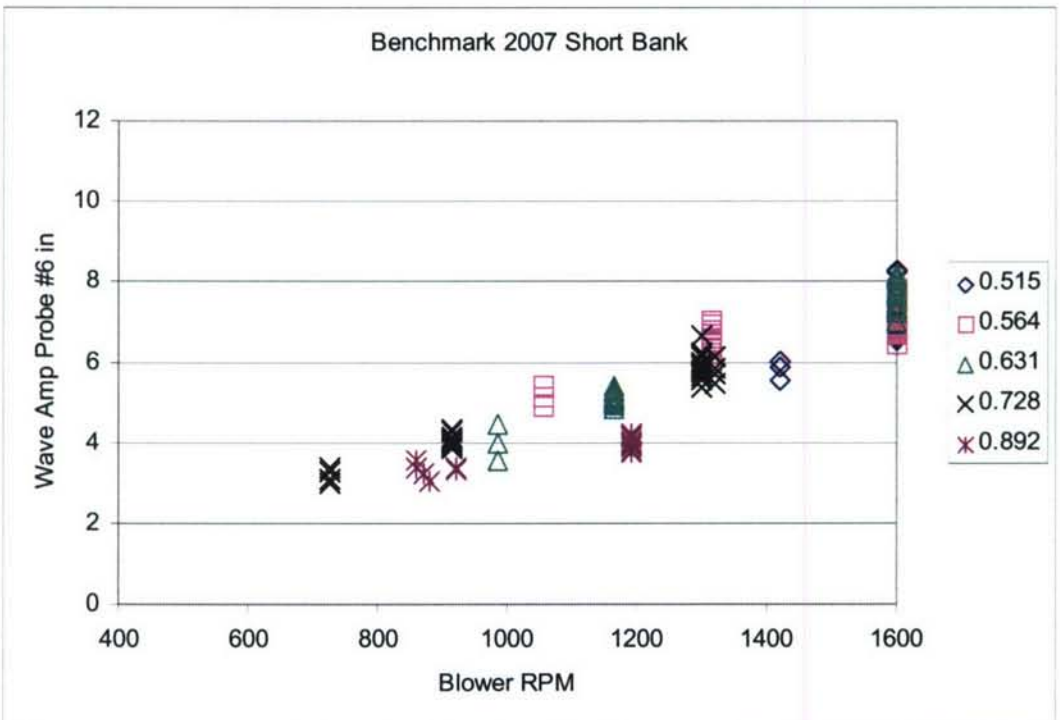

Figure 34. Benchmark Probe#6 wave amplitude variation by frequency for short bank.

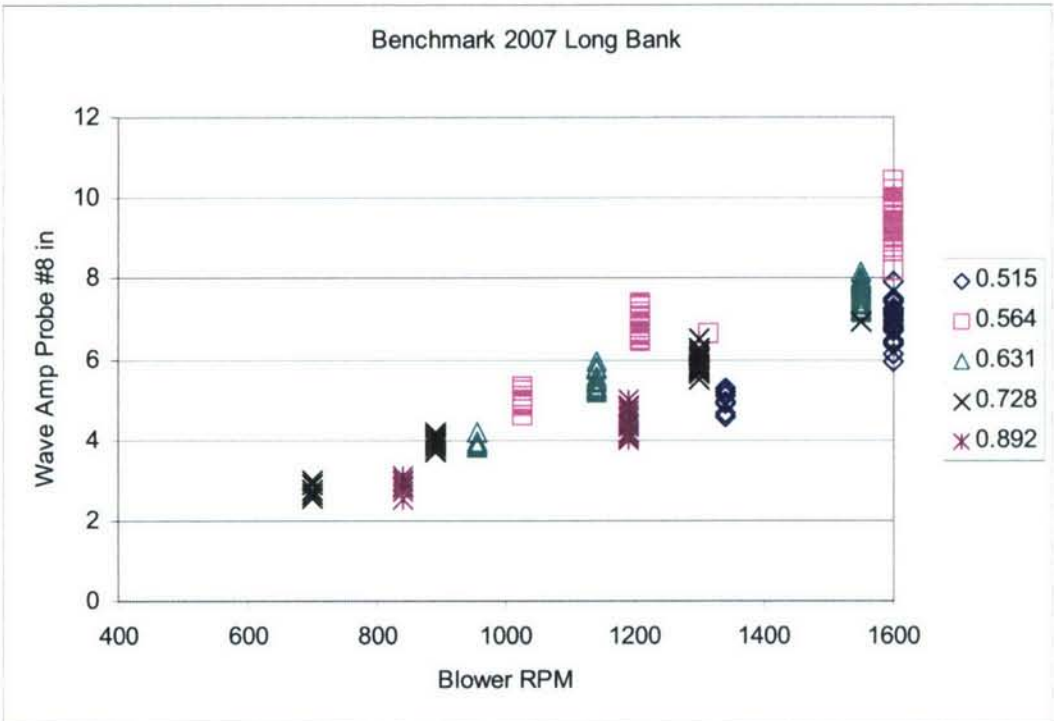

Figure 35. Benchmark Probe#8 wave amplitude variation by frequency for long bank.

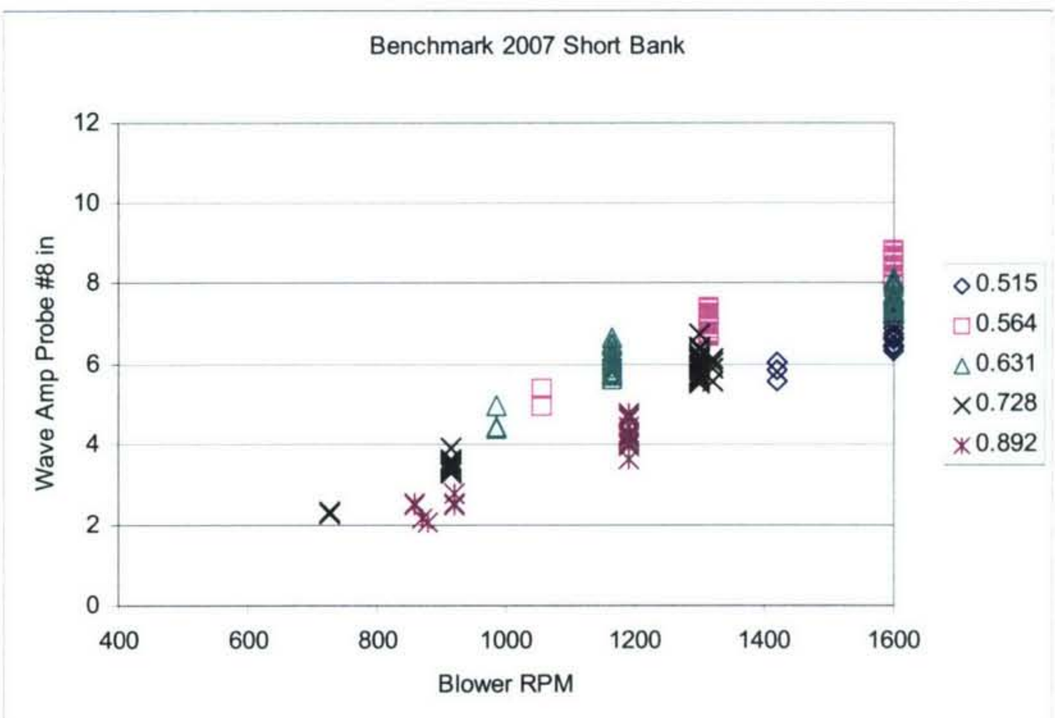

Figure 36. Benchmark Probe#8 wave amplitude variation by frequency for short bank.

HARMONIC DISTORTION

The metric used for wave quality was A1/RQ0. This gives a measured harmonic distortion, but not spatial, temporal, and run-to-run variation. This ratio compares the first harmonic amplitude to mathematical amplitude of a sine wave having the same measured root mean square (RMS). A value of 1.0 indicates perfect, or nearly perfect, sinusoidal waves.

Wave slope is a function of wave length (wave frequency) and wave amplitude (blower speed). The steeper the wave, the more non-linear the wave is. The more non-linear the wave is, the lower the value of A1/RQ0. The detailed October 2004 analysis shows reasonable correlation with Stokes 2nd order waves (see Figure 22, for example). In addition, to the inherent non-linearity, the data dropouts at steeper waves also reduce A1/RQ0.

Figure 37 shows average A1/RQ0 for all the data runs by average inverse wave slope (wave length/wave height). Probes #3, #4, #5, and #6 were used for the average. Four data clusters are present, representing 1/10, 1/12, 1/15, and 1/20 wave slopes. For analysis, data with A1/RQ0 values less than 0.85 were ignored.

For shallow waves, up to 1/20 wave slope, A1/RQ0 is easily over 0.95, and often approaching 1.00. This is expected, as these waves are nearly linear.

A1/RQ0 drops as was wave slope increases to an average value of 0.905 for 1/10 waves. The scatter also increases due to the previously mentioned non-linearity and measurement difficulty. An A1/RQ0 cutoff value of 0.85 captures the good data for all wave slopes.

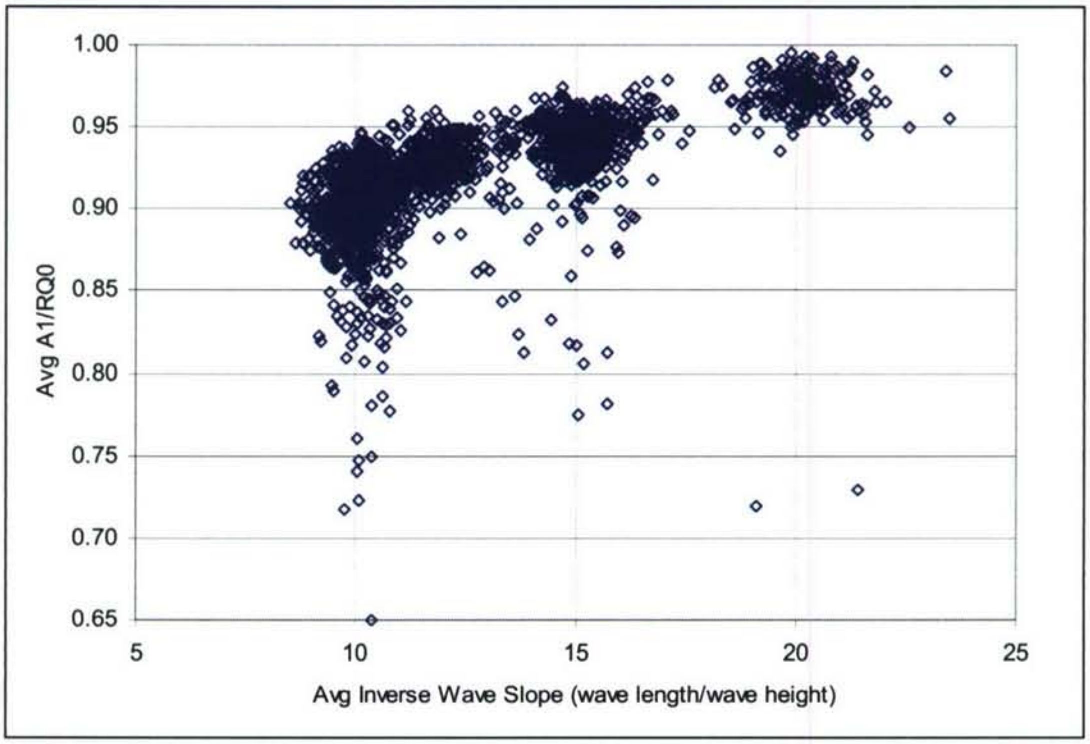

Figure 37. A1/RQ0 for all data runs by 1/wave steepness (wavelength/wave height).

DATA MACRO USE

An Excel workbook, *RWExtractor_v2.xls*, including macros, was developed to easily assemble and plot the data for the report. The macros extract the wave data from the regular wave analysis files and associated condition data from the electronic log file. The extracted data set is then grouped by like conditions into a table. A separate macro plots the wave data by probe. The same macros can be used to process future data for comparison to the benchmark data set.

RWExtractor_v2 is run by filling in the white cells on the Settings worksheet and clicking on the appropriate macro button working from top to bottom. See Figure 38 for a screen shot of the Settings worksheet.

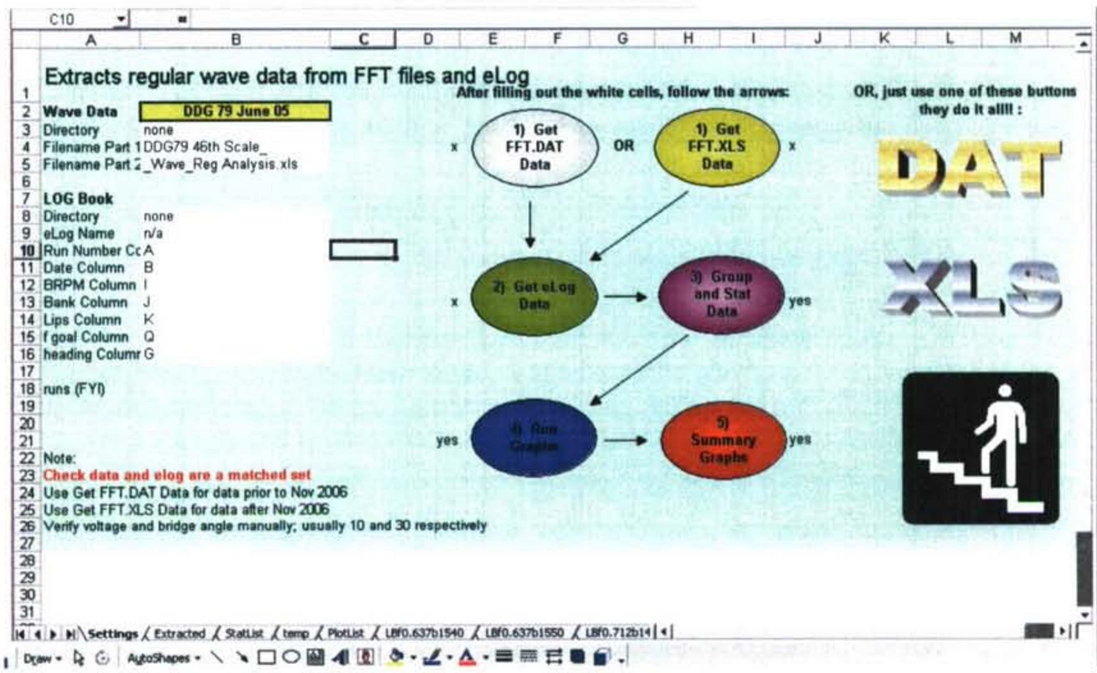

Figure 38. Screen shot of Settings worksheet.

Depending on the regular wave analysis file format, the user should either click **Get FFT.DAT Data** or **Get FFT.XLS Data**. The data are extracted from the run files to the Extracted worksheet. Next the electronic log file data are gathered by clicking on **Get eLog Data**. These data are also written to the Extracted worksheet. The user should verify the wave data are for the same test as the electronic log as the only relation between them is run number.

The next button to click is **Group and Stat Data**. This macro takes the data from Extracted, copies it to temp and groups it by wavemaker bank, frequency, and blower speed. Statistics are then done for each group and saved on the StatList worksheet.

The **Run Graphs** button generates plots from all the run data on temp of wave height by probes, wave frequency, and blower speed. Each run is its own series, or line.

The final button, **Summary Graphs**, generates plots from the data on StatList on separate chart sheets for each group.

CONCLUSIONS

The Maneuvering and Seakeeping Basin pneumatic wavemakers, like all wavemakers, produce waves that can vary spatially, temporally, within a run, and between runs. This report examined regular wave data from 2004 to 2007 to quantify the variation in wave amplitude with respect to those different parameters. Over 2700 individual runs and 186 separate conditions were examined. A benchmark set of data was developed to provide a yardstick for future wavemaker performance.

The generated waves are a function of wavemaker settings including: blower speed, frequency, stabilizer lip depth, wavemaker bank, and span voltage. The benchmark data set records all these settings and the resultant wave amplitudes for comparison with future data.

The pneumatic wavemakers, while not perfect, can yield consistent results assuming the wavemaker system is properly tuned. For a given wavemaker settings, the generated waves repeat within a small error band. The measured wave frequency is within one percent of the target frequency. The average variation of wave amplitude for all conditions is 5.81±2.13% on the long bank and 6.17±3.02% on the short bank. Generally, wave height variation of 5-6% is accepted as normal operations.

There does not appear to be any seasonal variation in wavemaker settings for a given wave amplitude, though the wavemaker controller upgrade did have an effect. A more detailed examination of atmospheric changes, such as air density and pressure, may show variations in wave output, though they cannot be considered a major uncertainty factor. By monitoring the waves as the test proceeds, this variability can be minimized with small adjustments to blower speed.

Wave slope does not vary unacceptably with location in the MASK or with time at a specified location. Actual wave steepness measured in MASK is typically slightly higher than target steepness. Percent variability of wave height with space and time is about 5% for $H/\lambda=1/15$ and 1/20 and about 10% for $H/\lambda=1/10$. Data dropouts may result in wave height predicted by trough-to-peak analysis being less than actual wave height.

This page intentionally left blank.

APPENDIX A: ALL CONDITION LINE PLOTS

The plots in this Appendix, Figures A-1-A-30, show the variation in wave amplitude for different probes, frequencies, blower speeds, and stabilizer lip settings. The data are grouped for each plot by blower speed and stabilizer lip setting. The wave amplitude is the average value of all the data for a given frequency, wavemaker bank, and probe sorted again by stabilizer lip setting and blower speed. The blower speeds are averaged over 60 RPM bins to avoid having a separate curve for each small change in blower speed. The reported blower speed is the average blower speed; hence, the values are typically not round numbers.

Also, because all the data are used, but not sorted or filtered by test date, identifying any temporal variation, outside of expanded error bars, is impossible. The error bars represent two standard deviations about the mean.

This page intentionally left blank.

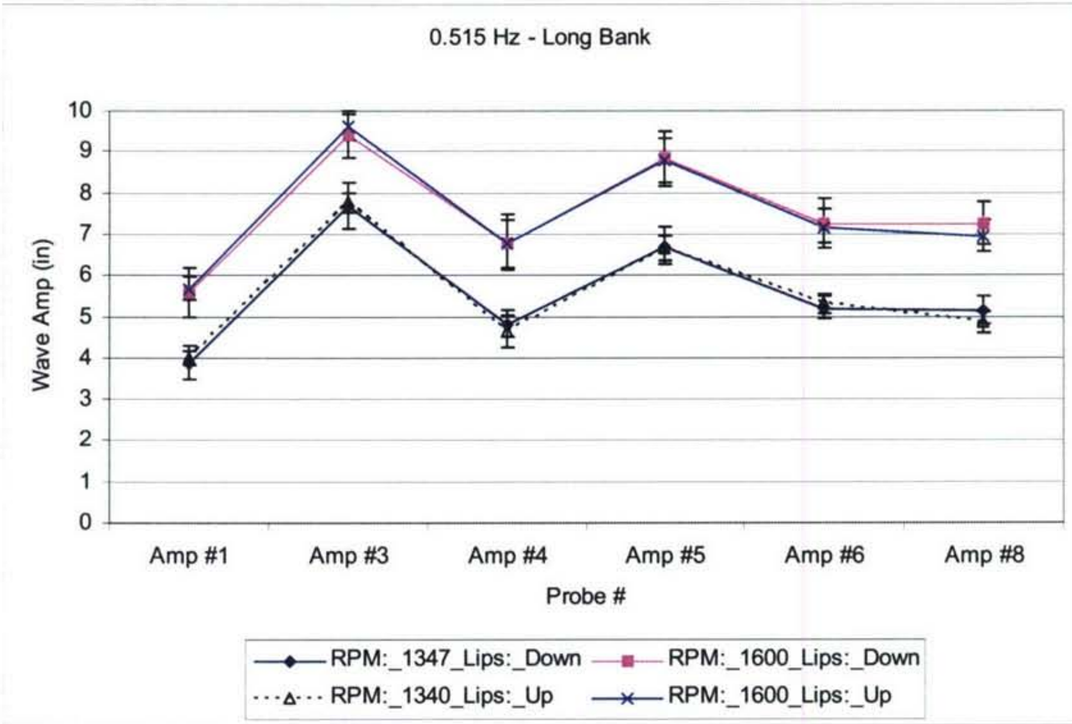

Figure A-1. Wave amplitude by probe, blower speed, lip setting for 0.515 Hz on the long bank.

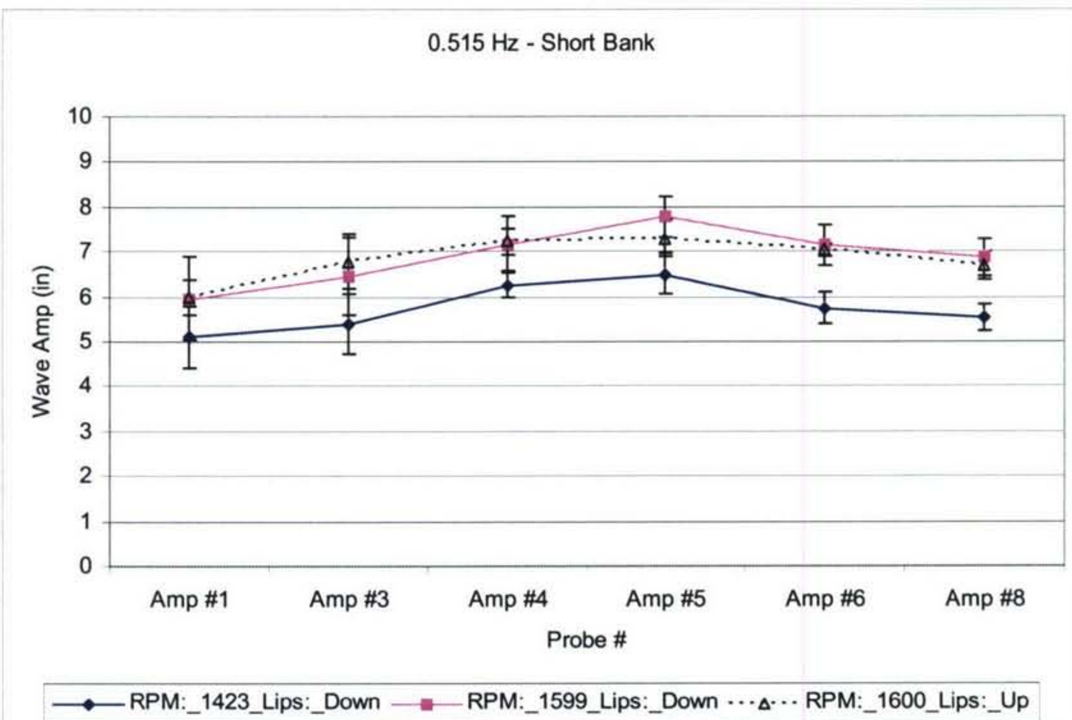

Figure A-2. Wave amplitude by probe, blower speed, lip setting for 0.515 Hz on the short bank.

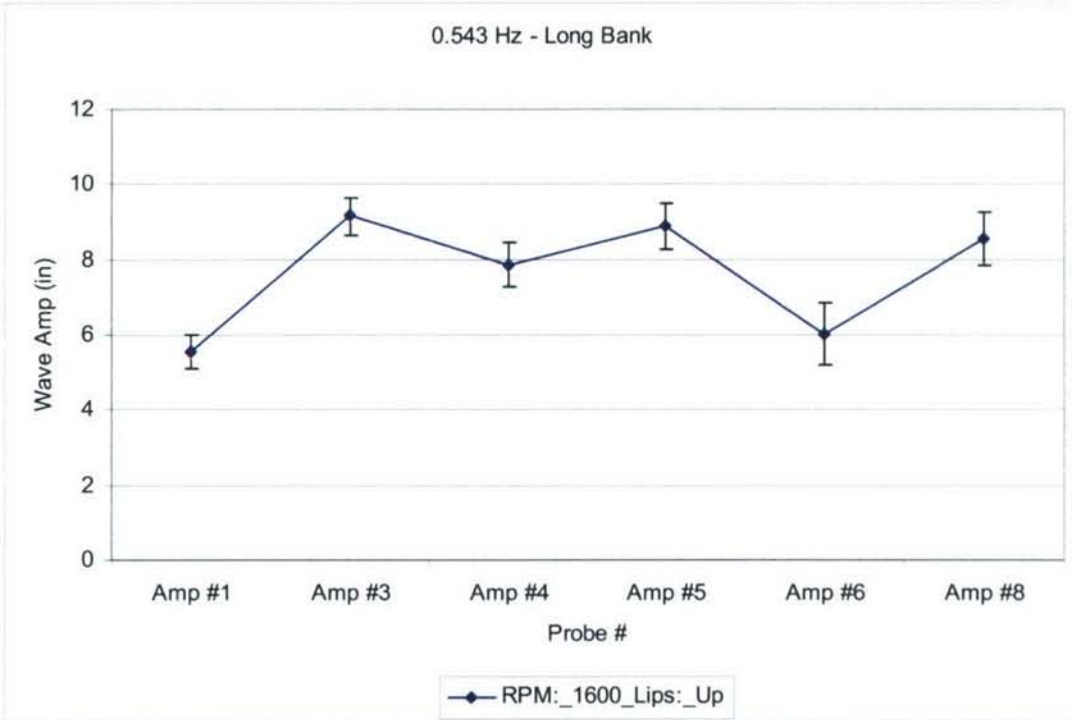

Figure A-3. Wave amplitude by probe, blower speed, lip setting for 0.543 Hz on the long bank.

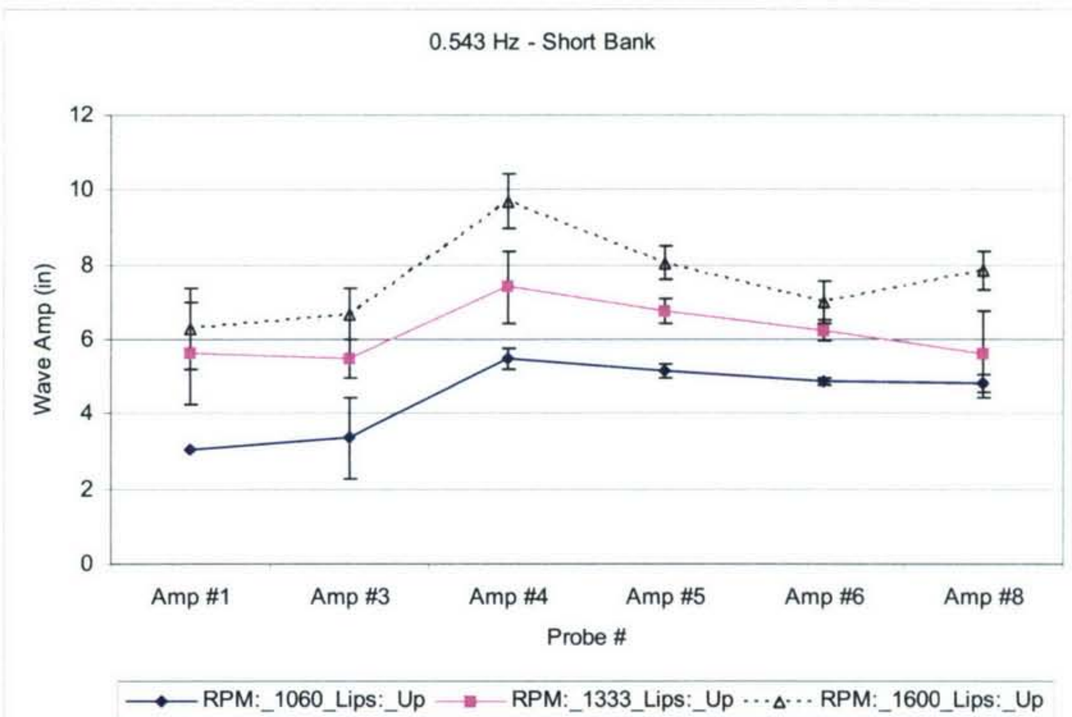

Figure A-4. Wave amplitude by probe, blower speed, lip setting for 0.543 Hz on the short bank.

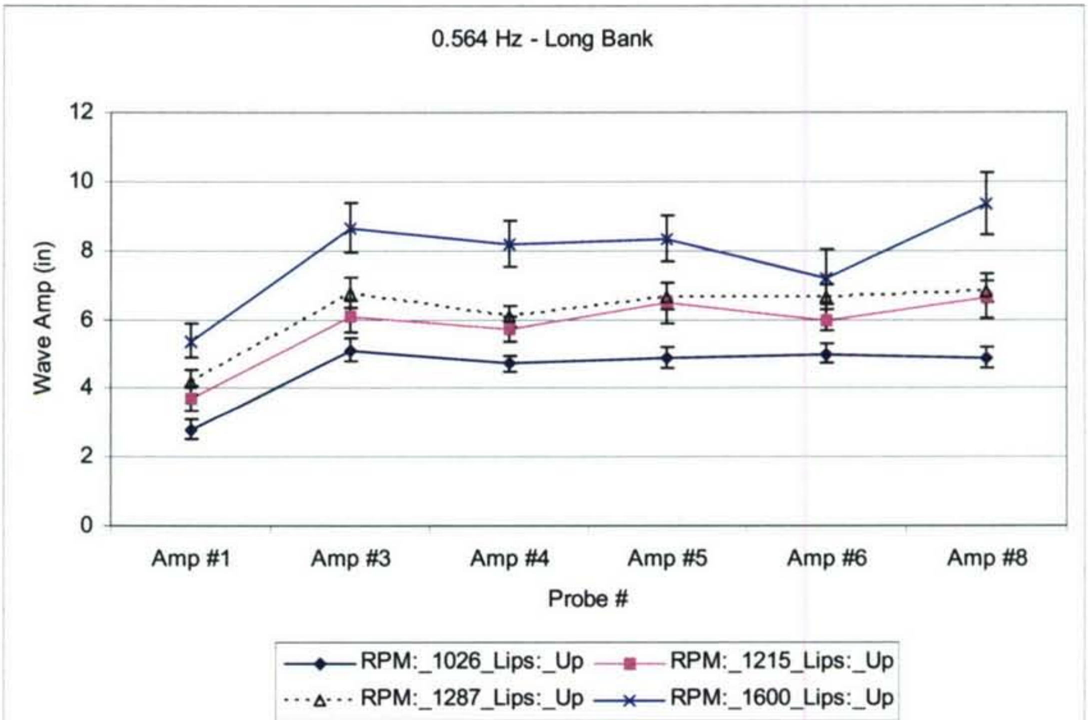

Figure A-5. Wave amplitude by probe, blower speed, lip setting for 0.564 Hz on the long bank.

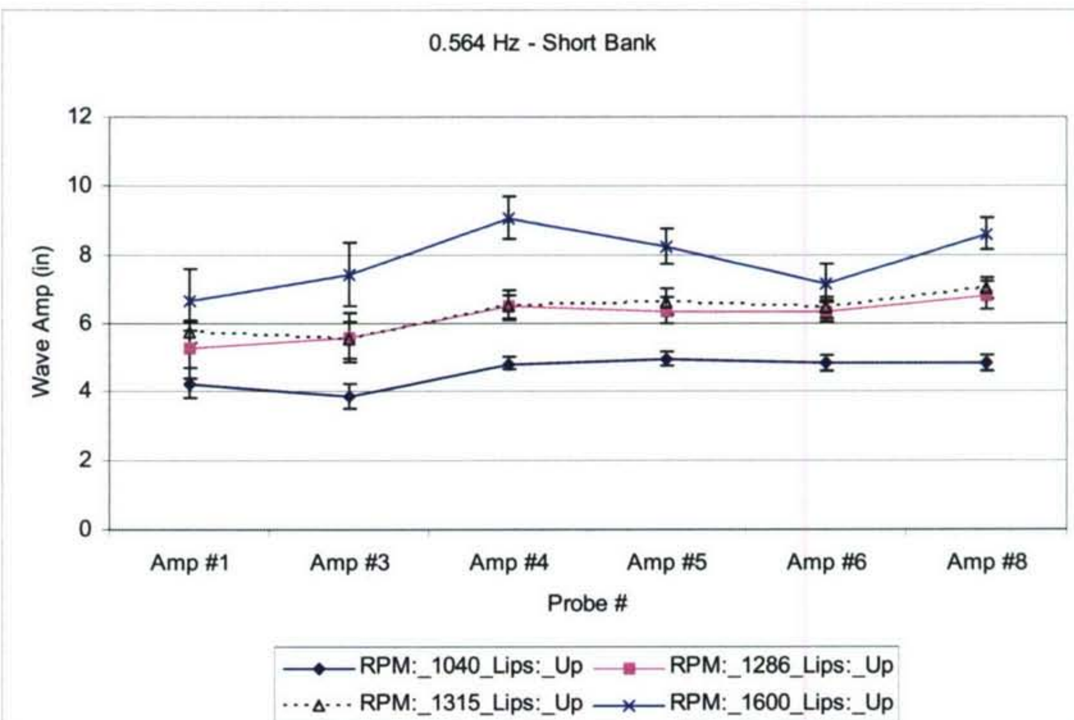

Figure A-6. Wave amplitude by probe, blower speed, lip setting for 0.564 Hz on the short bank.

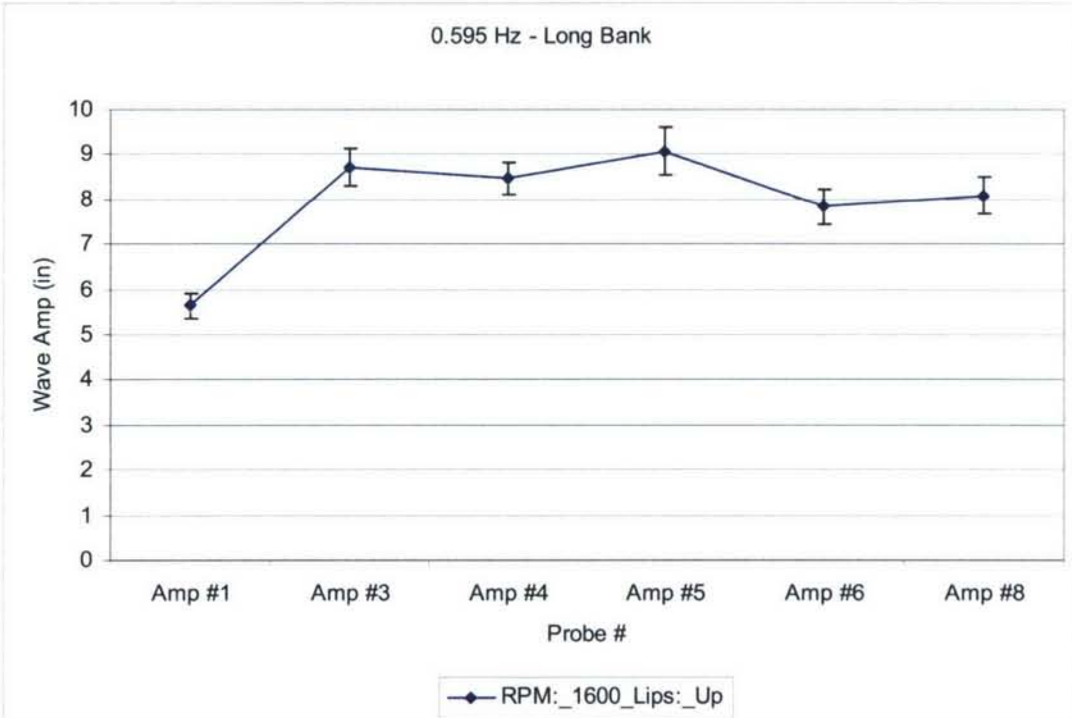

Figure A-7. Wave amplitude by probe, blower speed, lip setting for 0.595 Hz on the long bank.

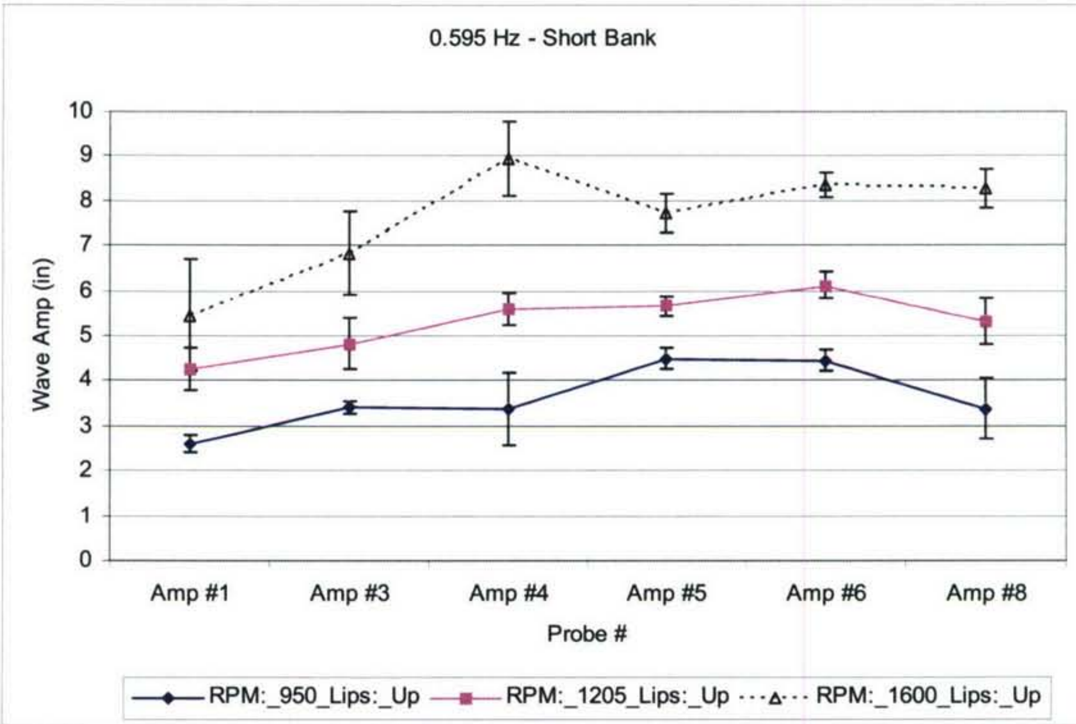

Figure A-8. Wave amplitude by probe, blower speed, lip setting for 0.595 Hz on the short bank.

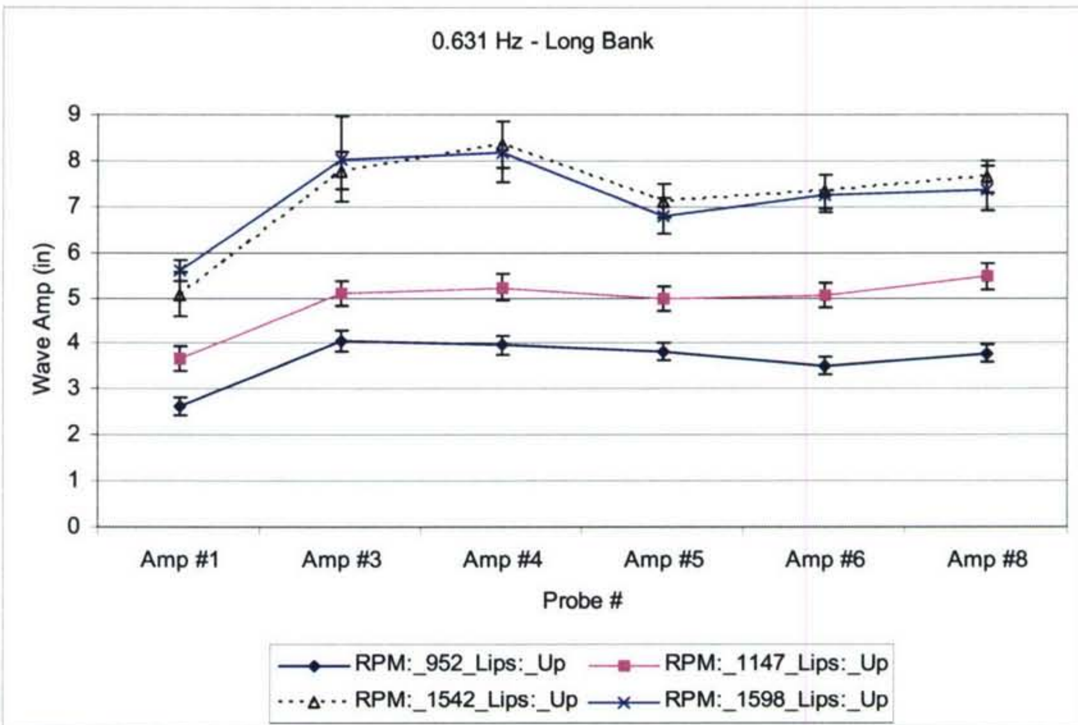

Figure A-9. Wave amplitude by probe, blower speed, lip setting for 0.631 Hz on the long bank.

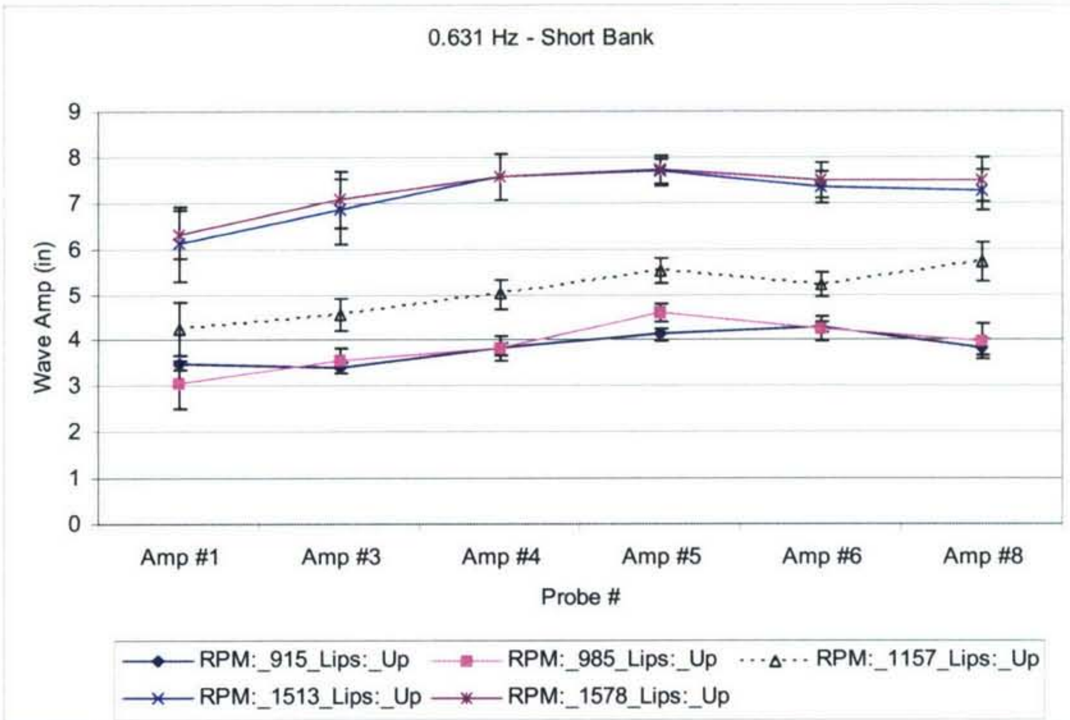

Figure A-10. Wave amplitude by probe, blower speed, lip setting for 0.631 Hz on the short bank.

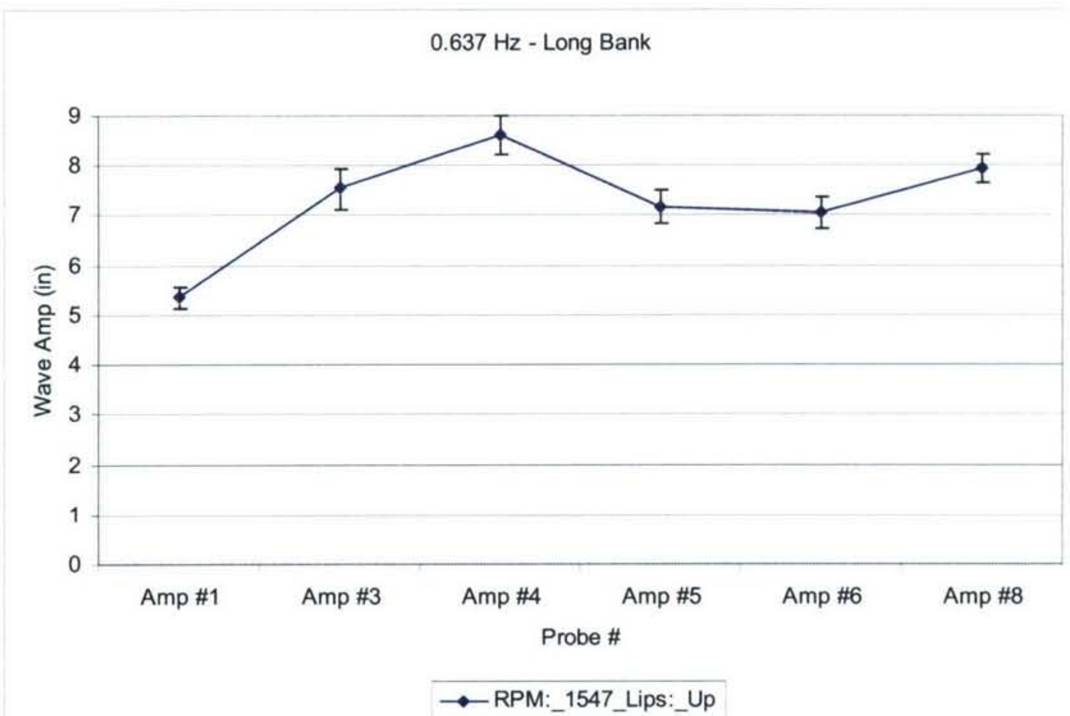

Figure A-11. Wave amplitude by probe, blower speed, lip setting for 0.637 Hz on the long bank.

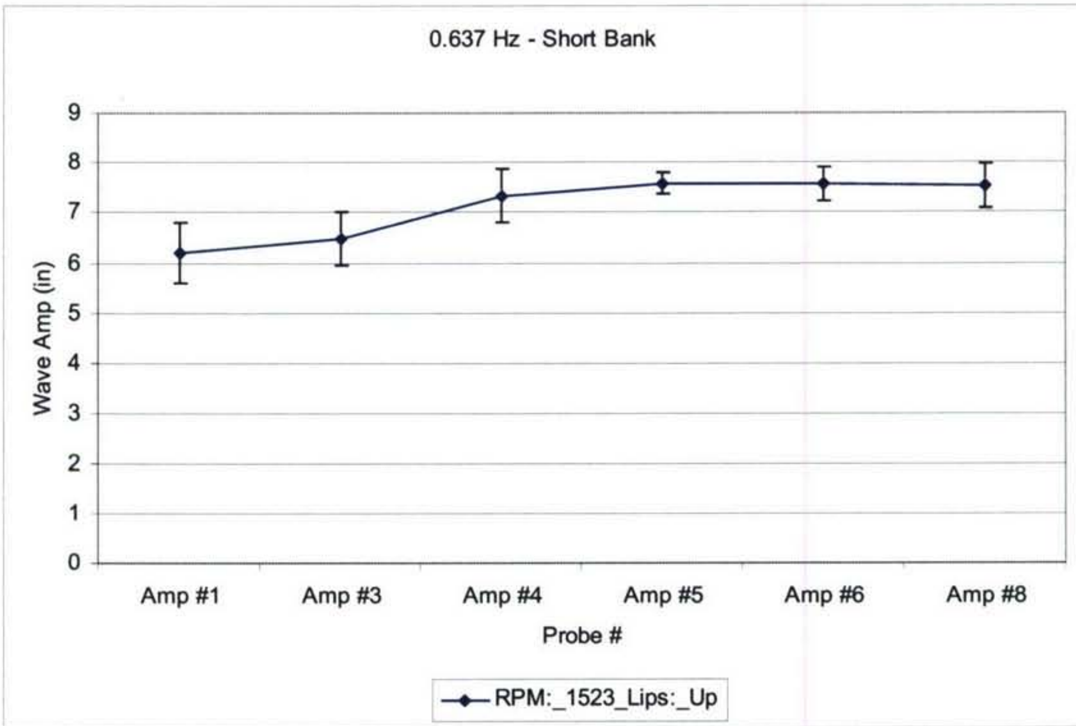

Figure A-12. Wave amplitude by probe, blower speed, lip setting for 0.637 Hz on the short bank.

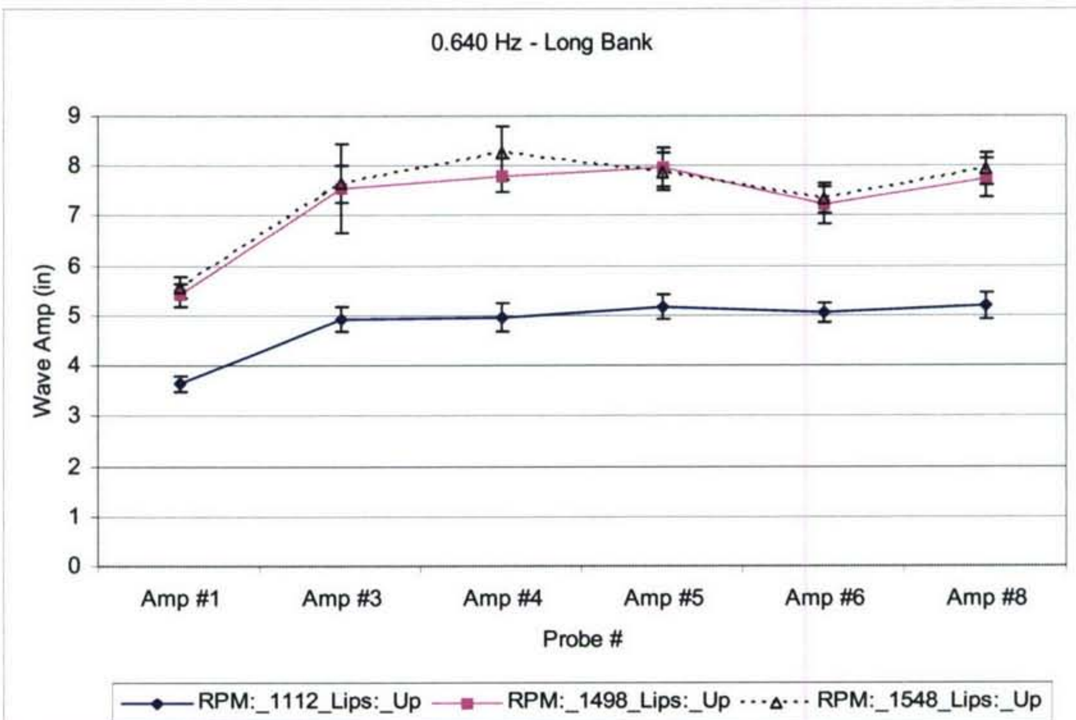

Figure A-13. Wave amplitude by probe, blower speed, lip setting for 0.640 Hz on the long bank.

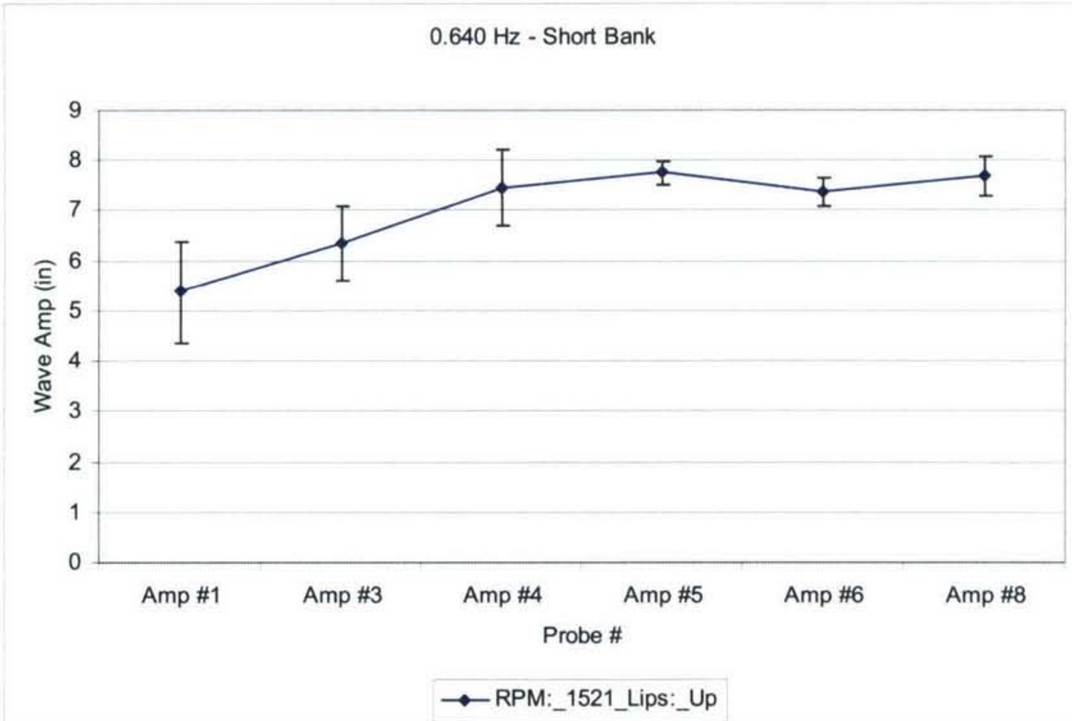

Figure A-14. Wave amplitude by probe, blower speed, lip setting for 0.640 Hz on the short bank.

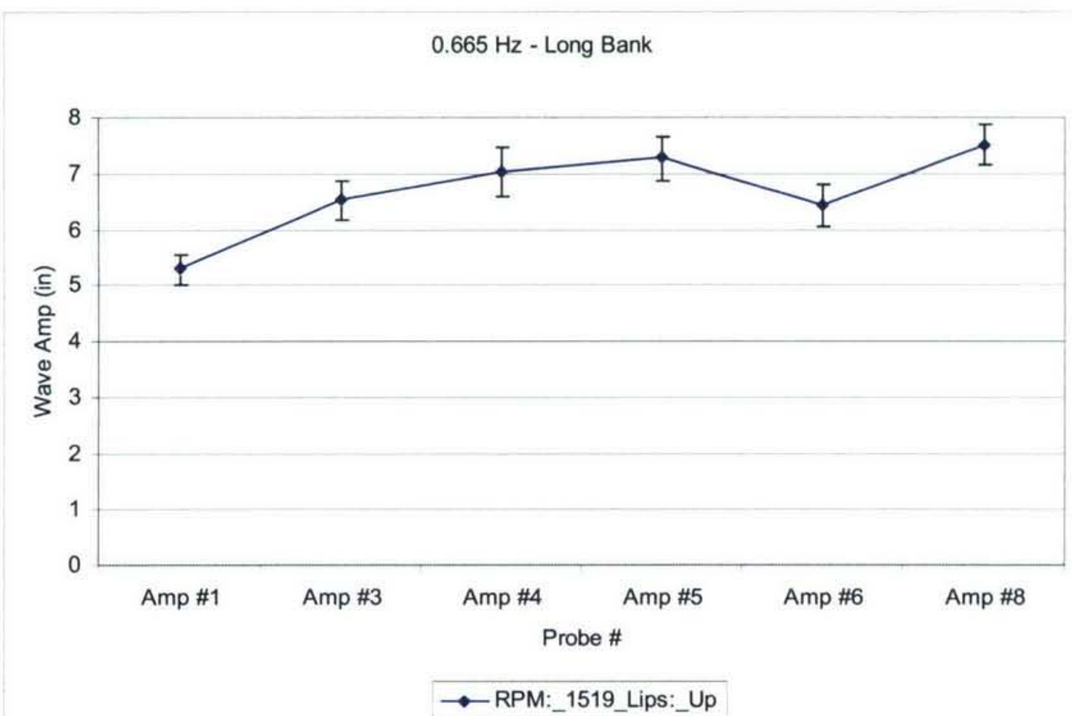

Figure A-15. Wave amplitude by probe, blower speed, lip setting for 0.665 Hz on the long bank.

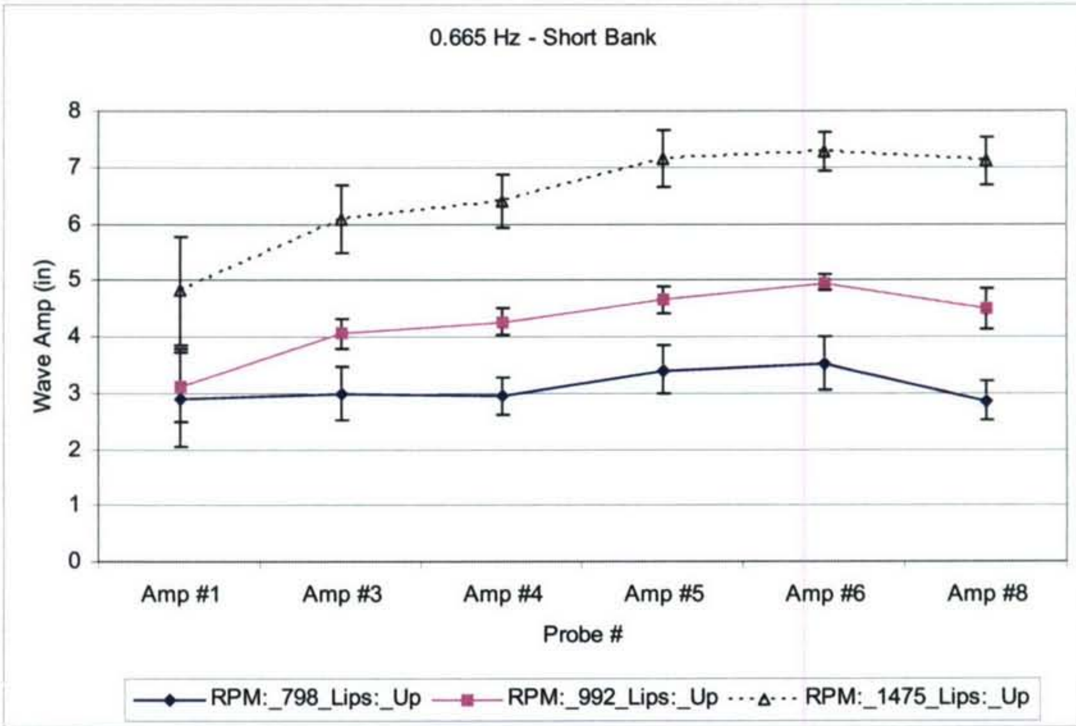

Figure A-16. Wave amplitude by probe, blower speed, lip setting for 0.665 Hz on the short bank.

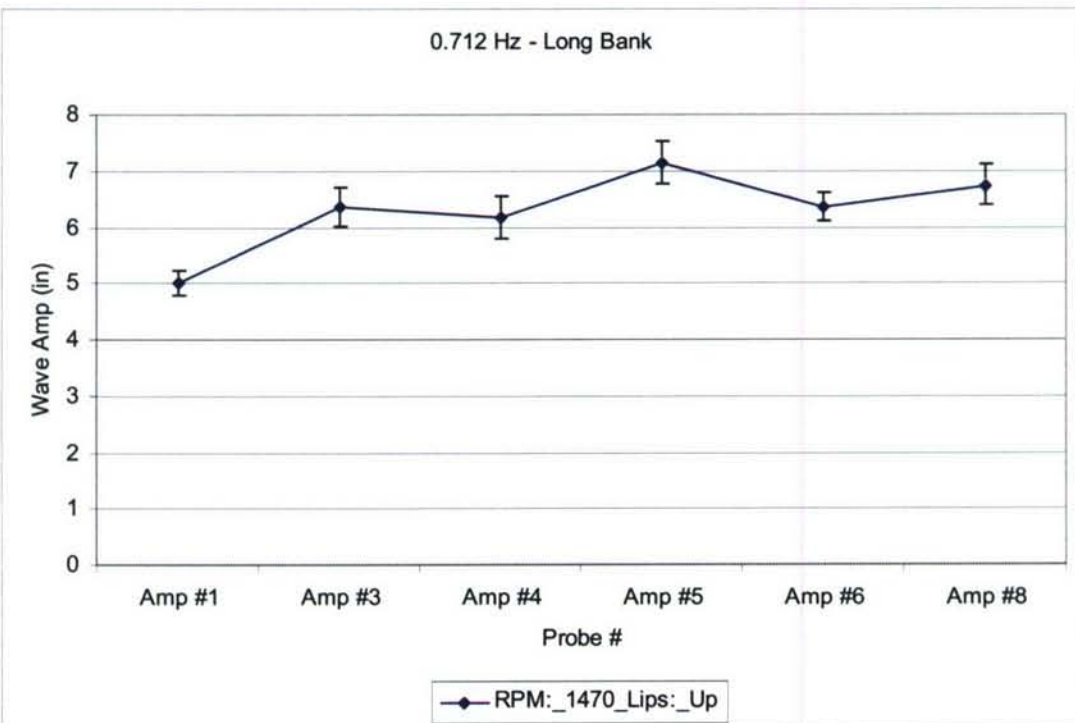

Figure A-17. Wave amplitude by probe, blower speed, lip setting for 0.712 Hz on the long bank.

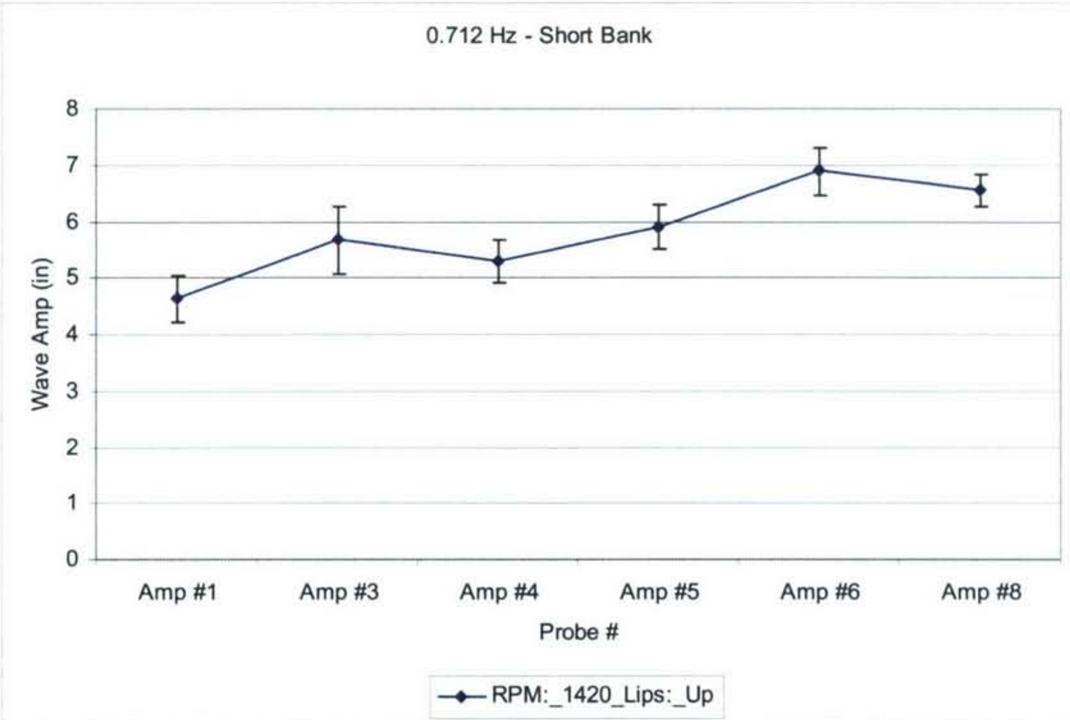

Figure A-18. Wave amplitude by probe, blower speed, lip setting for 0.712 Hz on the short bank.

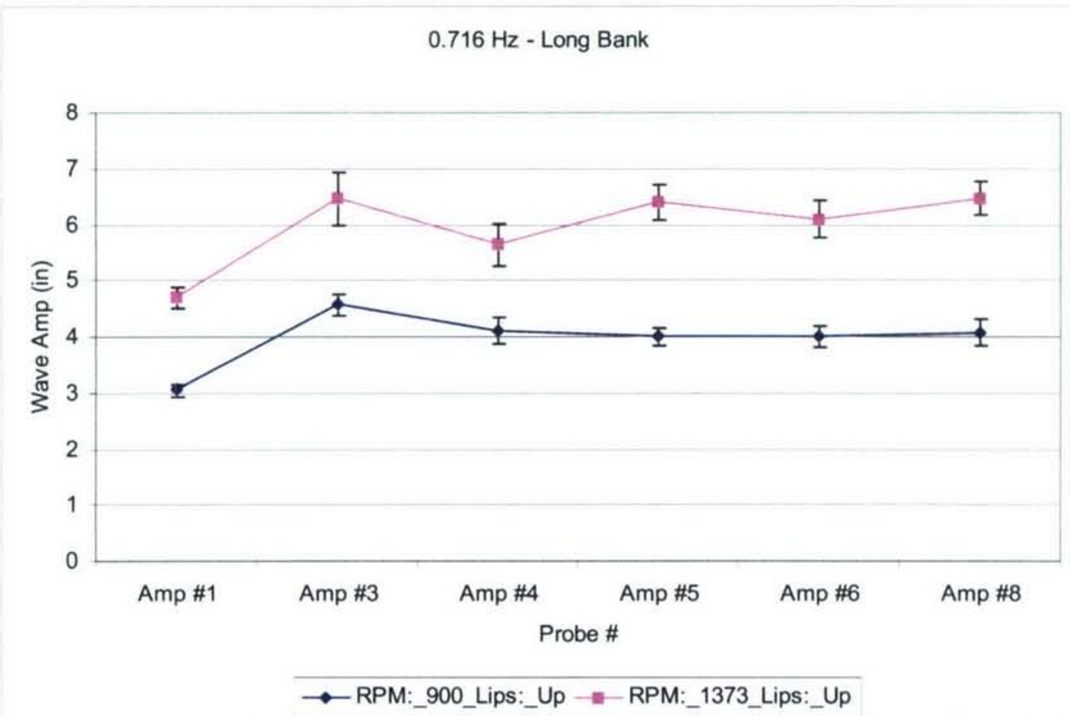

Figure A-19. Wave amplitude by probe, blower speed, lip setting for 0.716 Hz on the long bank.

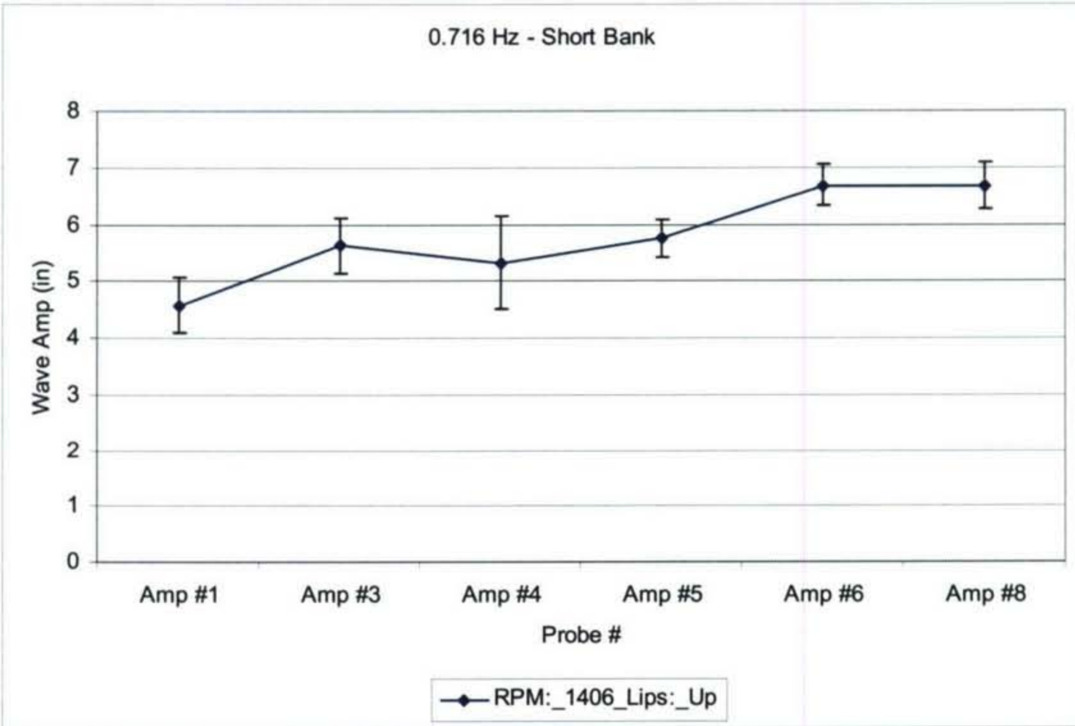

Figure A-20. Wave amplitude by probe, blower speed, lip setting for 0.716 Hz on the short bank.

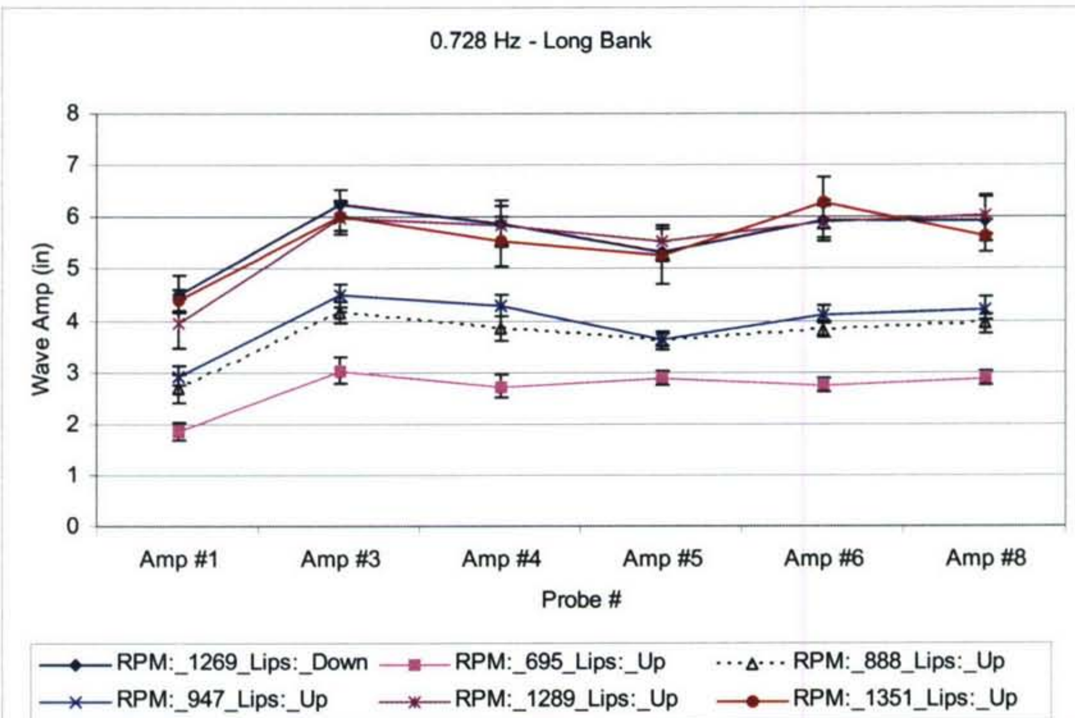

Figure A-21. Wave amplitude by probe, blower speed, lip setting for 0.728 Hz on the long bank.

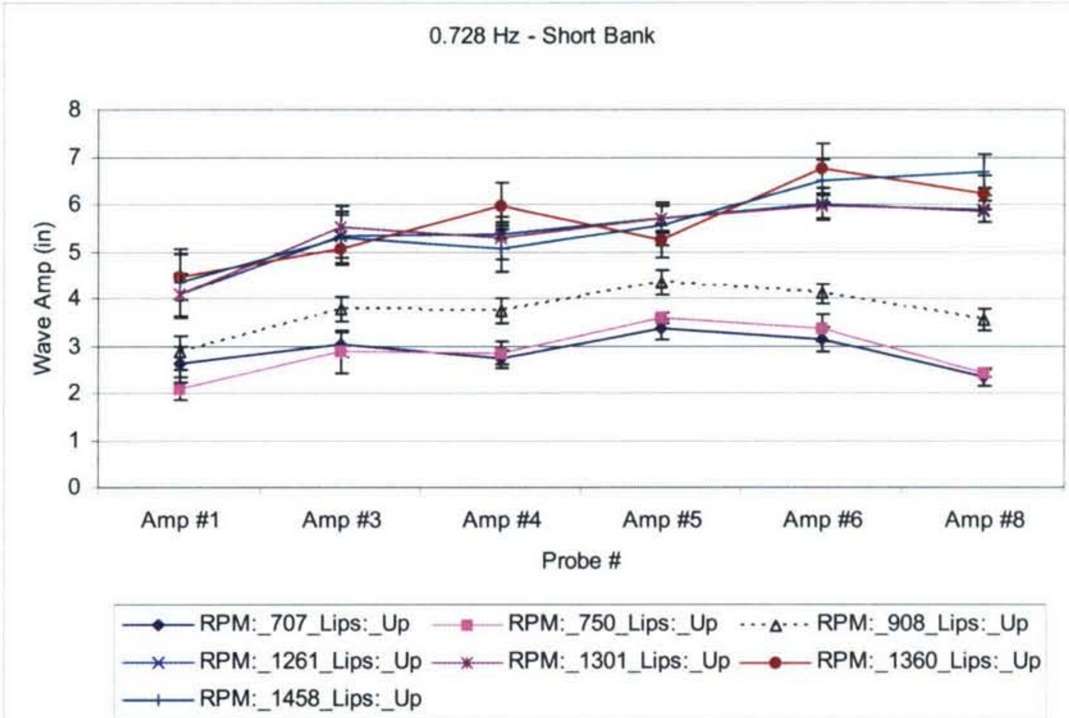

Figure A-22. Wave amplitude by probe, blower speed, lip setting for 0.728 Hz on the short bank.

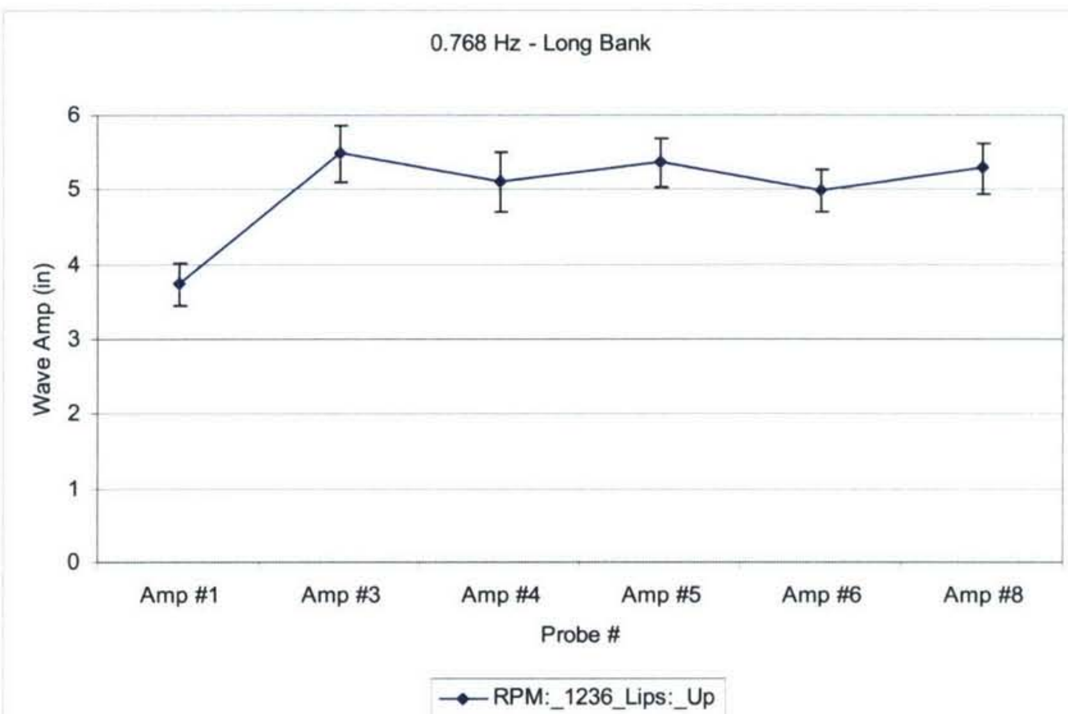

Figure A-23. Wave amplitude by probe, blower speed, lip setting for 0.768 Hz on the long bank.

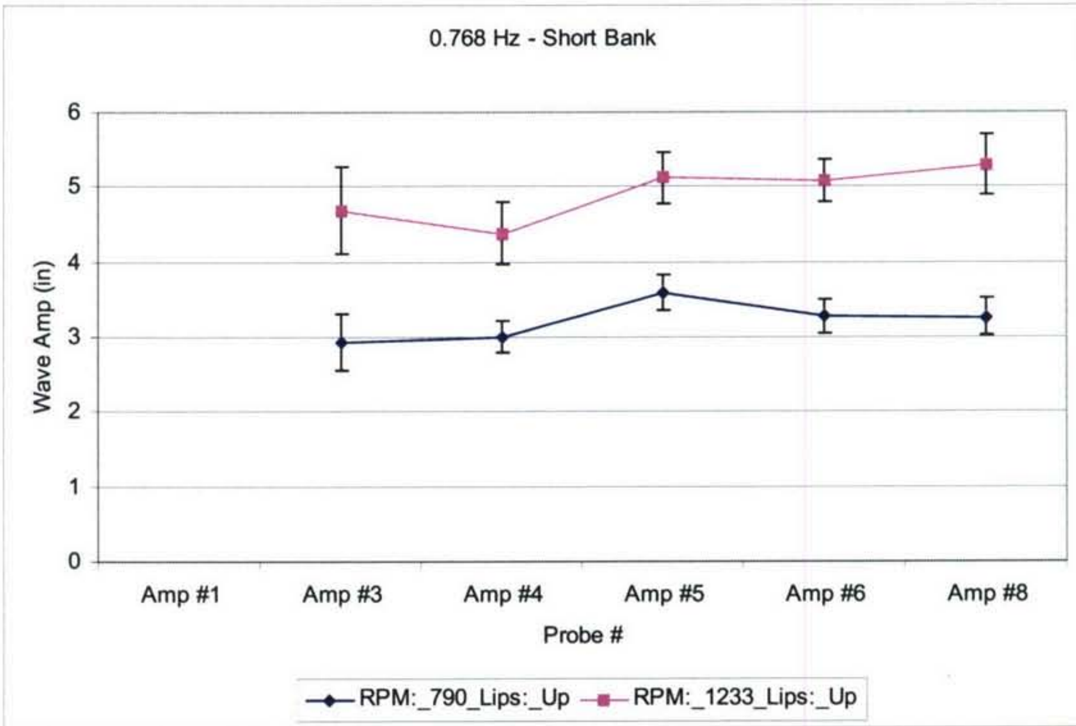

Figure A-24. Wave amplitude by probe, blower speed, lip setting for 0.768 Hz on the short bank.

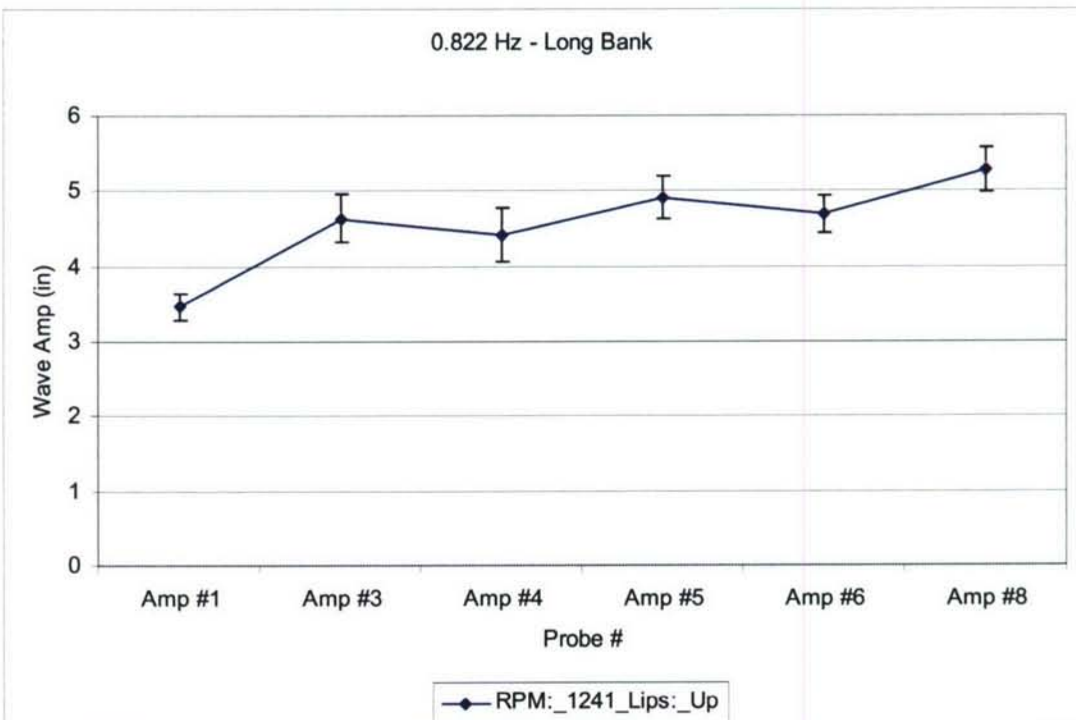

Figure A-25. Wave amplitude by probe, blower speed, lip setting for 0.822 Hz on the long bank.

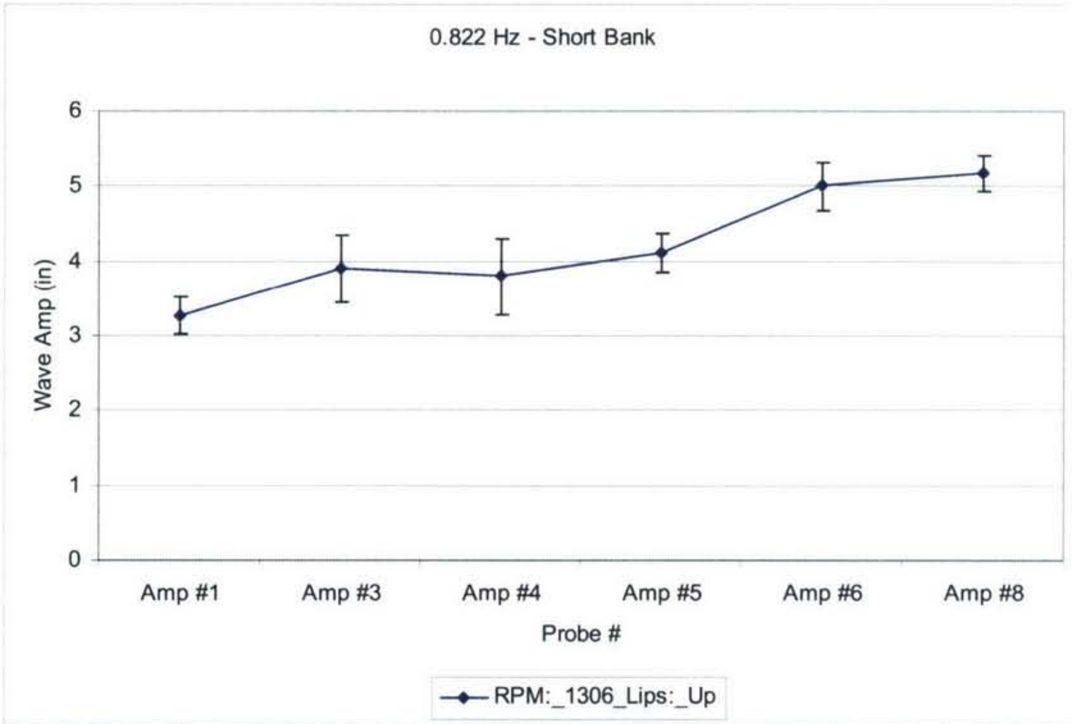

Figure A-26. Wave amplitude by probe, blower speed, lip setting for 0.822 Hz on the short bank.

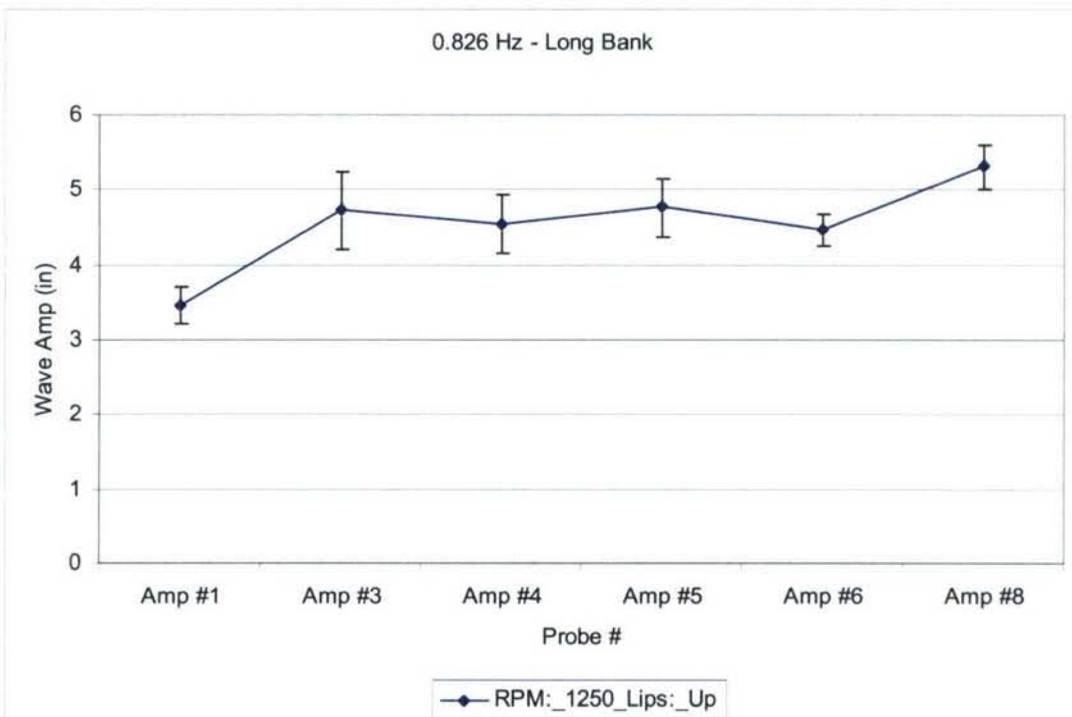

Figure A-27. Wave amplitude by probe, blower speed, lip setting for 0.826 Hz on the long bank.

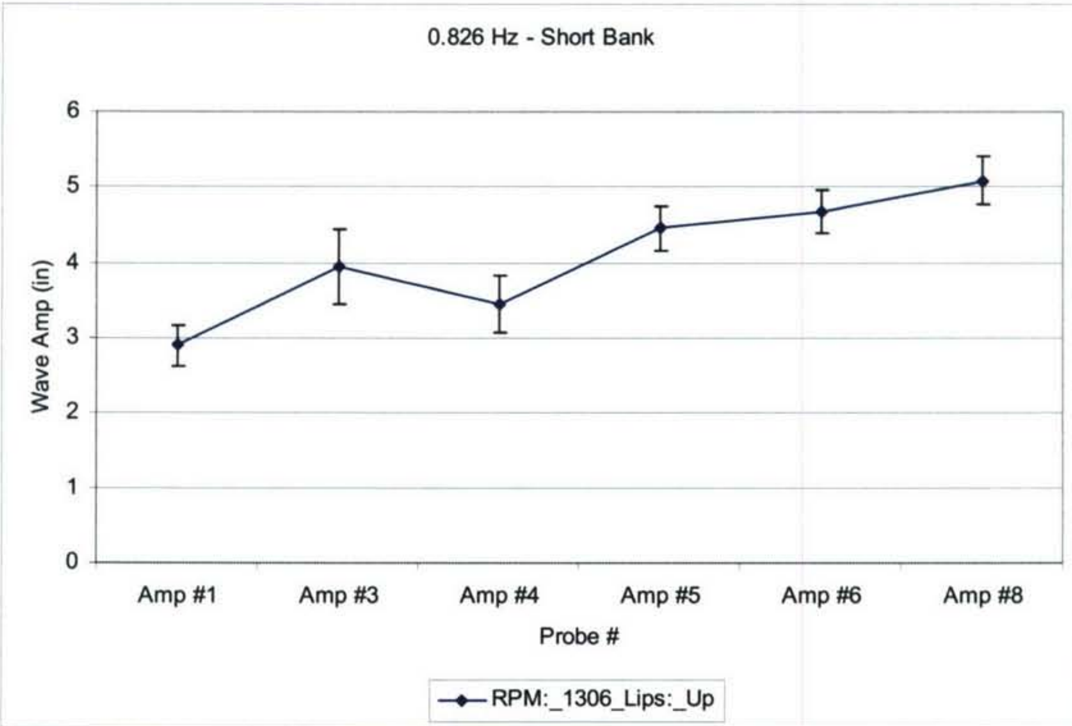

Figure A-28. Wave amplitude by probe, blower speed, lip setting for 0.826 Hz on the short bank.

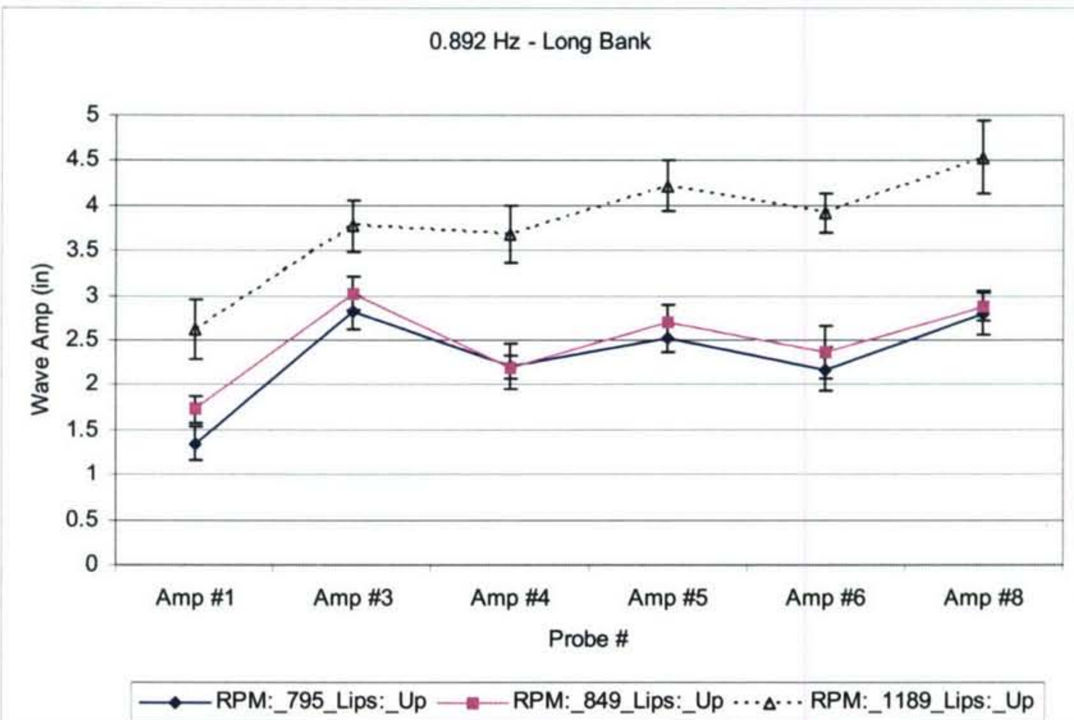

Figure A-29. Wave amplitude by probe, blower speed, lip setting for 0.892 Hz on the long bank.

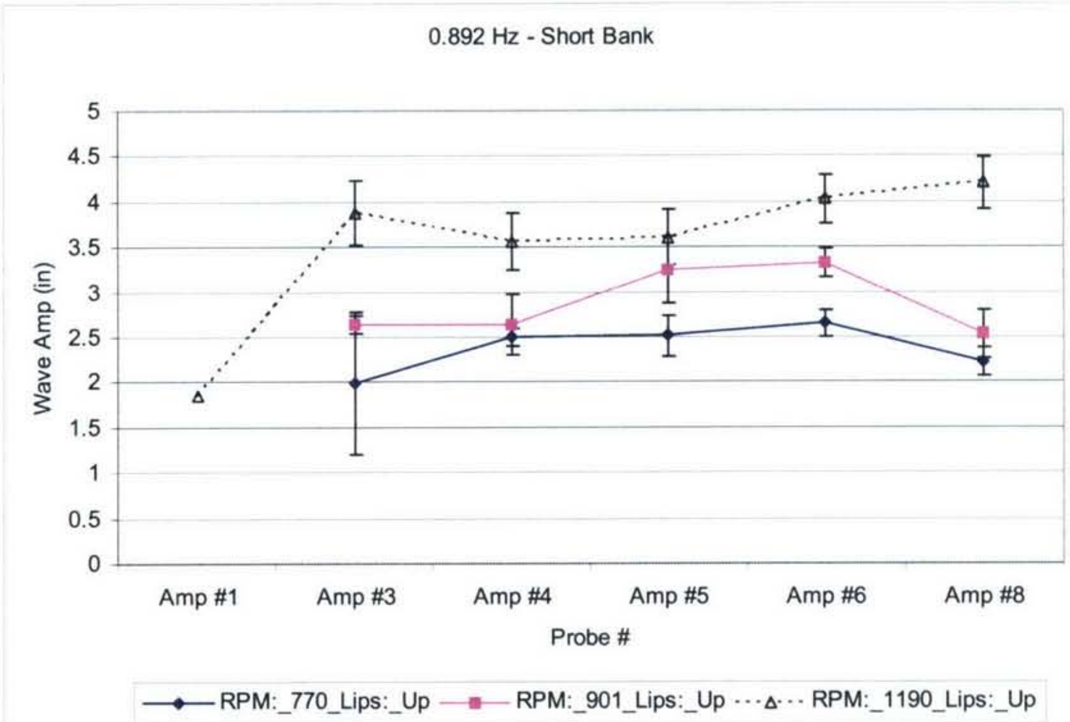

Figure A-30. Wave amplitude by probe, blower speed, lip setting for 0.892 Hz on the short bank.

APPENDIX B: ALL CONDITION RUN BY RUN VARIATION

Table B-1. Coefficient of variation as percentage for all conditions for long bank and bridge at 30 degrees. Shaded cells are outliers.

Freq Hz	Blower RPM	Lips	Amp #1 in	Amp #3 in	Amp #4 in	Amp #5 in	Amp #6 in	Amp #8 in
0.515	1340	Up	4.01	2.96	8.77	4.48	4.75	5.24
0.515	1340	Down	3.18	4.19	6.77	7.67	4.13	5.16
0.515	1350	Down	9.41	5.03	8.33	7.18	4.21	6.97
0.515	1350	Down	15.17	7.08	5.00	5.33	5.90	7.16
0.515	1600	Down	10.11	5.36	7.73	7.54	7.28	4.63
0.515	1600	Down	8.08	5.55	9.94	5.73	4.75	6.62
0.515	1600	Up	4.87	3.30	9.80	6.12	5.58	5.48
0.515	1600	Down	8.78	4.49	7.83	7.98	8.13	7.12
0.543	1600	Up	5.93	4.58	7.59	6.49	14.00	5.81
0.543	1600	Up	9.85	6.31	7.07	6.48	13.01	5.82
0.564	1025	Up	10.05	9.78	7.10	1.98	3.06	7.84
0.564	1025	Up	9.18	6.96	4.81	4.91	4.61	4.60
0.564	1025	Up	9.36	4.66	3.79	4.41	2.29	4.51
0.564	1030	Up	6.41	6.65	3.99	9.13	7.16	7.54
0.564	1210	Up	8.63	5.83	4.00	4.00	3.86	4.68
0.564	1225	Up	13.17	10.47	9.78	15.42	6.74	14.94
0.564	1280	Up	3.17	8.15	5.10	7.72	4.92	4.01
0.564	1290	Up	8.11	5.22	3.88	4.24	5.86	3.49
0.564	1290	Up	10.20	4.88	4.09	5.00	4.15	4.97
0.564	1600	Up	4.62	6.47	10.10	10.59	11.08	6.47
0.564	1600	Up	6.21	5.18	4.67		8.97	4.16
0.564	1600	Up	5.86	4.00	6.54	5.07	4.95	3.63
0.564	1600	Up	7.70	7.44	3.90		9.97	19.16
0.564	1600	Up	8.00	5.36	6.41	5.63	8.48	4.59
0.564	1600	Up	9.47	3.74	7.22	5.59	12.53	5.18
0.564	1600	Up	6.87	8.22	6.98	6.81	6.99	4.63
0.564	1600	Up	12.76	6.86	6.16	4.77	5.87	5.22
0.595	1600	Up	4.72	4.11	3.22	6.23	5.37	5.74
0.595	1600	Up	5.61	5.21	4.97	5.49	4.69	4.09
0.631	935	Up	5.00	3.50	3.26	3.92	2.96	2.68
0.631	950	Up	9.78	4.34	4.98	4.26	3.81	3.48
0.631	955	Up	4.67	7.61	6.43	3.13	7.24	8.29
0.631	955	Up	4.98	5.21	4.24	5.93	5.46	3.15
0.631	970	Up	10.33	7.85	6.58	5.10	3.49	3.59
0.631	1140	Up	8.98	3.09	3.81	4.43	1.86	3.45
0.631	1140	Up	8.95	5.54	5.44	4.83	5.07	4.08
0.631	1150	Up	2.88	4.11	3.77	6.11	3.66	4.70
0.631	1150	Up	8.20	5.22	4.84	3.74	5.25	5.28
0.631	1150	Up	7.78	5.05	5.29	4.56	3.61	3.68
0.631	1150	Up	4.86	6.61	5.42	4.96	5.53	3.13

Table B-1. Coefficient of variation as percentage for all conditions for long bank and bridge at 30 degrees. (Continued).

Freq Hz	Blower RPM	Lips	Amp #1 in	Amp #3 in	Amp #4 in	Amp #5 in	Amp #6 in	Amp #8 in
0.631	1520	Up	3.86	5.55	8.72	4.13	5.60	3.43
0.631	1525	Up	3.97	5.29	7.30	5.14	4.62	4.24
0.631	1530	Up	8.65	4.04	4.68	5.30	4.79	5.36
0.631	1530	Up	7.93	5.77	4.77	4.87	4.75	4.70
0.631	1540	Up	17.62	2.78	4.53	4.55	6.10	3.93
0.631	1550	Up	3.87	6.95	5.60		5.58	4.97
0.631	1550	Up	3.89	4.24	5.18	5.64	3.80	4.88
0.631	1550	Up	6.76	3.74	5.18	3.25	4.96	3.68
0.631	1560	Up	3.44	2.94	5.33	3.26	3.62	3.59
0.631	1570	Up	3.77	3.65	6.50	6.27	4.93	3.55
0.631	1580	Up	2.95	3.04	5.91		4.58	2.22
0.631	1590	Up	3.54	3.21	6.28	3.90	4.18	3.55
0.631	1600	Up	3.11	5.38	4.50	3.58	6.03	4.10
0.631	1600	Up	4.67	5.79	4.66		6.16	7.91
0.637	1540	Up	4.16	5.89	3.98	3.43	3.70	3.93
0.637	1550	Up	3.85	5.07	4.77	4.22	4.07	3.24
0.640	1120	Up	5.03	3.83	6.79	3.12	1.59	4.41
0.640	1510	Up	4.09	4.24	3.70	2.81	4.73	1.60
0.640	1550	Up	4.34	4.88	5.96	2.84	3.43	4.33
0.665	1520	Up	5.89	4.87	5.44	5.22	5.48	6.15
0.665	1520	Up	4.27	5.39	6.67	5.25	5.05	3.44
0.712	1470	Up	3.85	4.83	6.28	3.94	4.18	4.47
0.712	1470	Up	4.27	6.23	5.90	5.72	3.65	6.27
0.716	900	Up	3.56	3.89	5.48	4.19	4.81	5.78
0.716	1370	Up	4.33	7.45	6.82	5.17	5.37	4.48
0.728	670	Up	3.67	4.00	4.14	4.44	4.05	4.79
0.728	700	Up	9.17	7.69	4.29	2.95	2.87	4.37
0.728	700	Up	15.89	7.84	8.06	3.13	4.16	3.49
0.728	700	Up	6.70	9.58	12.98		4.80	4.14
0.728	700	Up	5.14	12.94	7.00	5.70	4.66	5.74
0.728	890	Up	10.03	2.99	6.27	3.83	3.97	6.38
0.728	890	Up	10.38	5.30	4.73	2.69	4.14	5.43
0.728	890	Up	4.42	4.59	6.86	4.96	5.42	3.86
0.728	890	Up	5.18	7.02	5.46	4.12	2.88	3.16
0.728	950	Up	5.23	4.04	3.00	4.19	2.79	4.42
0.728	1265	Up	4.46	5.47	5.43	4.26	5.96	7.30
0.728	1265	Down	6.99	3.43	8.62	2.62	8.05	8.77
0.728	1275	Up	5.23	3.61	4.77	5.24	6.15	5.50
0.728	1275	Up	5.45	4.66	6.27		8.07	8.79
0.728	1300	Up	16.27	4.57	4.37	4.92	4.14	5.27
0.728	1300	Up	10.94	4.27	5.69	5.54	4.89	4.69
0.728	1300	Up	10.35	4.17	4.85	2.44	4.57	4.54
0.728	1300	Up	7.34	5.86	5.66	5.01	4.91	3.60
0.728	1360	Up	5.42	5.14	8.45	10.22	7.47	6.11

Table B-1. Coefficient of variation as percentage for all conditions for long bank and bridge at 30 degrees. (Continued).

Freq HZ	Blower RPM	Lips	Amp #1 in	Amp #3 in	Amp #4 in	Amp #5 in	Amp #6 in	Amp #8 in
0.768	1230	Up	8.71	5.25	6.69	4.44	5.59	5.21
0.768	1230	Up	5.35	8.89	10.37	6.88	6.73	7.70
0.768	1270	Up	5.41	8.14	5.49	6.28	3.41	7.01
0.822	1240	Up	4.67	7.71	6.52	5.26	4.80	4.11
0.822	1240	Up	6.03	7.03	9.01	6.24	5.59	6.15
0.826	1250	Up	6.66	6.37	9.03	7.98	4.56	6.16
0.826	1250	Up	7.53	12.30	7.48	5.09	5.14	4.68
0.892	840	Up	6.63	5.99	2.81	4.53	5.52	4.67
0.892	840	Up	8.54	6.06	4.91	7.21	14.19	6.25
0.892	1190	Up	9.29	8.34	10.98	6.56	4.34	11.26
0.892	1190	Up	7.86	10.47	6.26	5.94	6.73	6.76
0.892	1190	Up	9.59	6.62	6.84	5.99	3.28	7.13
0.892	1190	Up	8.12	5.77	7.42	6.99	6.57	6.75
		Avg	6.95	5.68	6.09	5.27	5.44	5.33
		Std Dev	3.11	2.00	1.93	1.94	2.32	2.35

Table B-2. Coefficient of variation as percentage for all conditions for short bank and bridge at 30 degrees. Shaded cells are outliers.

Freq HZ	Blower RPM	Lips	Amp #1 in	Amp #3 in	Amp #4 in	Amp #5 in	Amp #6 in	Amp #8 in
0.515	1425	Down	8.96	12.27	3.99	3.88	6.67	3.03
0.515	1600	Down	6.31	18.81	8.94	4.20	4.55	3.59
0.515	1600	Down	22.14	8.64	5.84	4.90	6.15	5.78
0.515	1600	Down	13.64	14.18	9.33	4.70	7.00	7.85
0.515	1600	Up	6.55	9.23	4.00	5.59	1.98	4.53
0.515	1600	Down	8.38	10.81	3.96	5.13	5.05	2.26
0.515	1600	Down	7.43	14.01	7.64	7.96	6.65	5.51
0.543	1060	Up	0.00	32.25	4.99	3.93	1.94	4.86
0.543	1600	Up	11.99	6.76	3.16	6.09	7.45	7.26
0.543	1600	Up	16.01	11.73	6.81	5.01	7.47	4.44
0.564	1250	Up	15.43	9.19	7.29	5.84	1.73	5.35
0.564	1300	Up	19.83	11.93	4.80		3.28	4.07
0.564	1300	Up	3.40	12.55	8.10	6.18	4.45	6.12
0.564	1315	Up	4.58	9.88	5.58	4.93	4.12	5.90
0.564	1315	Up	5.42	9.40	4.62	6.72	5.44	2.97
0.564	1600	Up	10.21	10.42	3.10	5.68	6.78	2.96
0.564	1600	Up	6.40	14.42	5.84	5.43	5.96	5.26
0.564	1600	Up	4.66	14.26	2.72	7.88	10.70	5.64
0.564	1600	Up	6.88	8.23	5.17		6.79	5.64
0.564	1600	Up	16.08	13.48	5.72	4.99	7.31	5.21
0.564	1600	Up	5.66	12.25	4.31	7.25	5.99	5.04
0.564	1600	Up	7.85	9.78	5.02	7.37	6.14	4.30
0.564	1600	Up	16.11	9.92	6.02	5.65	5.41	2.35
0.595	1180	Up	12.88	8.07	4.22	3.41	1.84	15.84
0.595	1230	Up	2.52	16.11	7.76	2.85	5.37	4.73
0.595	1600	Up	23.76	10.94	8.03	5.14	3.77	5.25
0.595	1600	Up	16.73	13.50	6.79	3.85	3.10	4.92
0.631	915	Up	2.61	3.57	3.24		2.63	4.46
0.631	1130	Up	3.06	4.20	4.36	2.44	1.79	3.63
0.631	1155	Up	13.97	8.52	5.46	5.31	3.41	5.38
0.631	1155	Up	15.63	8.05	4.00		3.57	7.30
0.631	1160	Up	0.00	3.07	9.87	3.90	5.47	6.13
0.631	1165	Up	6.87	7.12	6.07		4.00	3.81
0.631	1165	Up	8.75	6.97	4.07	3.41	3.26	5.29
0.631	1485	Up	5.12	12.67	3.33	3.78	5.65	3.16
0.631	1500	Up	7.49	9.61	6.05		6.53	5.09
0.631	1520	Up	3.48	9.36	4.28		2.90	2.01
0.631	1520	Up	14.57	6.22	4.14	5.18	4.49	5.72
0.631	1520	Up	12.32	8.77	5.23	4.54	6.46	6.33
0.631	1540	Up	5.67	8.92	4.99	3.03	5.21	2.79
0.631	1540	Up	5.86	5.25	4.95		5.53	6.98
0.631	1540	Up	9.34	10.62	2.11	1.78	3.65	3.42
0.631	1550	Up		9.31	5.96	5.05	2.96	5.98
0.631	1560	Up		11.37	6.38		6.16	6.59

Table B-2. Coefficient of variation as percentage for all conditions for short bank and bridge at 30 degrees. (Continued).

Freq HZ	Blower RPM	Lips	Amp #1 in	Amp #3 in	Amp #4 in	Amp #5 in	Amp #6 in	Amp #8 in
0.631	1600	Up	7.31	7.43	7.62	3.04	3.87	5.54
0.631	1600	Up	9.21	6.77	5.16	4.04	3.12	4.25
0.631	1600	Up	7.24	4.10	4.05	3.07	4.20	3.46
0.637	1520	Up	5.23	9.43	6.00	2.57	2.99	5.67
0.637	1530	Up	4.69	5.29	5.00	3.19	4.81	4.64
0.640	1525	Up	20.01	11.05	6.23	3.36	4.14	2.62
0.640	1525	Up	18.13	5.55	5.77	2.57	2.65	3.24
0.665	780	Up			12.65	10.43	6.30	13.95
0.665	980	Up		5.02	6.54	5.70	3.87	8.45
0.665	1000	Up	0.00	7.32	5.44	5.18	1.75	6.52
0.665	1470	Up	12.75	7.78	5.25	5.34	4.92	5.30
0.665	1470	Up	14.19	10.77	5.83	4.85	3.94	5.73
0.665	1490	Up		6.22	7.56	3.13	4.11	3.60
0.712	1420	Up	7.53	11.15	7.84	5.16	4.72	3.93
0.712	1420	Up	10.16	5.62	5.78	6.59	4.92	4.26
0.716	1400	Up		6.56	10.14		5.01	3.85
0.716	1420	Up		10.21	15.88	4.92	6.79	8.10
0.728	875	Up	7.67	3.75	3.83	6.20	6.34	7.95
0.728	910	Up	15.27	5.59	3.69	3.89	3.70	6.28
0.728	910	Up	13.52	9.72	6.43	4.23	4.46	6.58
0.728	915	Up	7.53	8.45	8.70	4.30	6.09	7.08
0.728	915	Up	8.61	6.01	8.02	2.60	3.78	4.16
0.728	1225	Up	11.44	9.62	4.62	6.30	5.00	4.34
0.728	1240	Up	3.33	9.79	4.34	4.99	5.63	2.83
0.728	1240	Up	0.56	5.93	4.66		7.89	4.20
0.728	1260	Up	0.00	3.58	6.54	5.71	8.27	4.39
0.728	1280	Up	0.00	5.95	5.52	6.53	6.03	3.41
0.728	1280	Up	0.00	11.11	4.66	4.65	4.56	3.37
0.728	1290	Up	0.00	6.06	3.82	1.34	3.96	3.25
0.728	1300	Up	9.01	7.77	8.91	4.84	3.93	4.36
0.728	1300	Up	10.19	8.27	9.62	4.07	4.46	5.27
0.728	1360	Up	11.13	5.49	8.24	6.87	8.05	5.71
0.728	1460	Up	9.75	8.57	10.14	7.35	6.47	4.91
0.768	810	Up			9.36	6.61	3.36	6.88
0.768	1230	Up		8.35	8.61	5.94	5.73	5.49
0.768	1230	Up		8.38	8.76	5.75	6.33	4.80
0.768	1245	Up			8.58	2.31	4.41	4.47
0.822	1300	Up	4.21	0.60	12.53	6.83	3.56	3.41
0.822	1320	Up	3.29	9.45	13.63	4.86	8.36	5.41
0.826	1300	Up	9.63	10.50	11.94	6.75	6.09	6.13
0.892	770	Up			5.16	9.45	4.80	8.75
0.892	1190	Up		3.55	7.06	5.75	5.91	5.00
0.892	1190	Up			11.49	7.43	5.49	6.69
0.892	1190	Up		5.54	5.45	7.30	9.57	7.79
0.892	1190	Up		8.84	10.36	10.93	3.87	7.75
		Avg	8.30	8.85	6.48	5.15	4.99	5.35
		Std Dev	5.63	4.08	2.63	1.82	1.78	2.18

This page intentionally left blank.

REFERENCES

1. Stahl, R. G., "NSWCCD Wavemakers and Notes on Wavemaking," CRDKNSWC/HD-0369-12 (Jun 1998).

2. Stahl, R. G., "Ship Model Size Selection, Facilities, and Notes on Experimental Techniques," CRDKNSWC/HD-1448-01 (Jun 1998).

3. Foster, J. J., "Calibration of Wavemakers for the Generation of Regular Waves in the Harold E. Saunders Seakeeping Facility," Report 1918 (Oct 1964).

4. Smith, T. C., "MASK Basin 'A' Bank Wave Survey," NSWCCD-50-TR-1999/075 (Nov 1999).

5. Smith, T. C., "MASK Basin 'B' Bank Wave Survey," NSWCCD-50-TR-1999/076 (Nov 1999).

This page intentionally left blank.

DISTRIBUTION

DTIC	1

NSWC, CARDEROCK DIVISION INTERNAL DISTRIBUTION

Code	Name	Copies
3452TIC (electronic only)		1
5060 Walden		1
5100 Davis		1
5010 w/o enclosure		1
5500 Applebee		4
Smith		
Hanyok		
Hughes		